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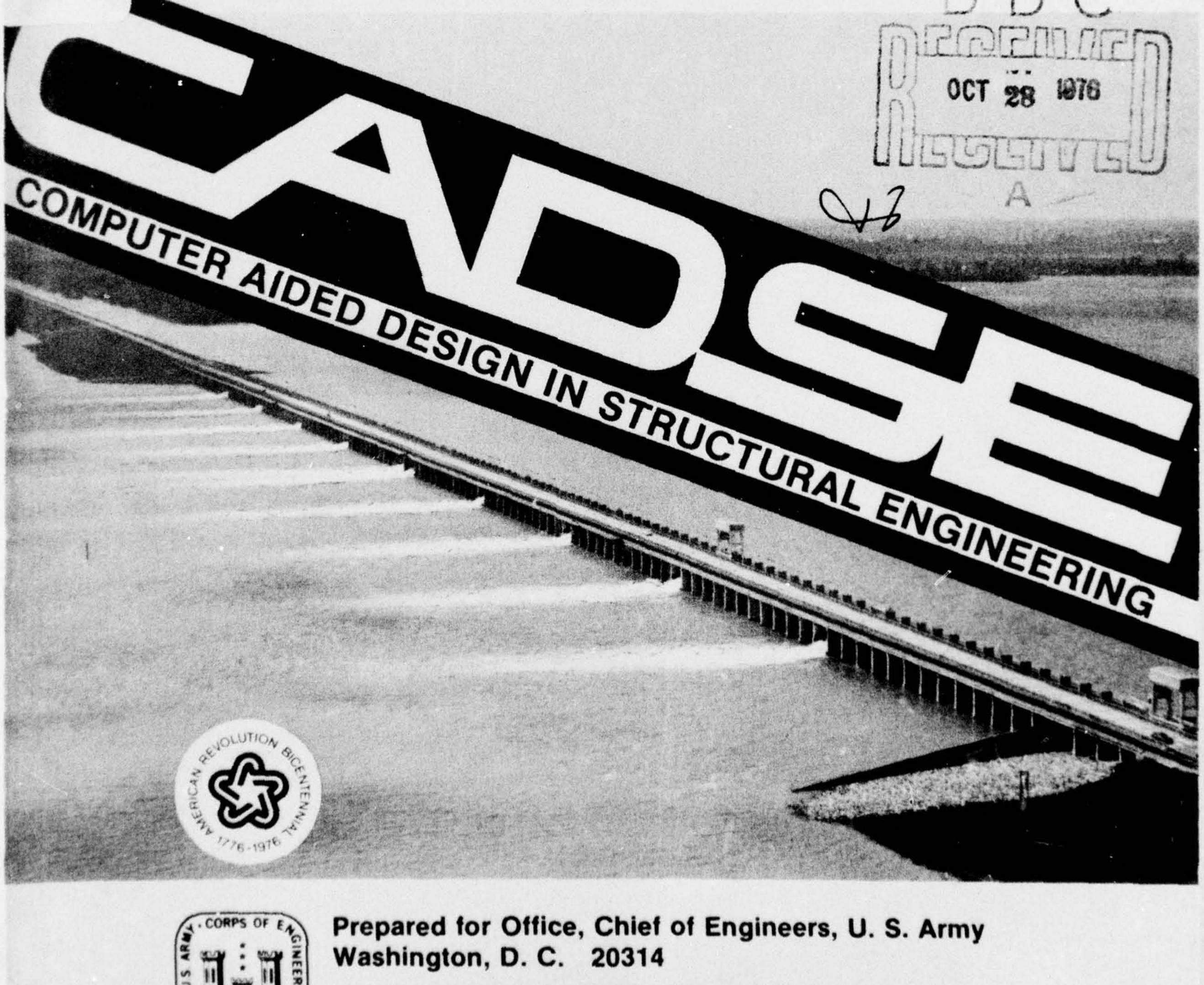
22-26 September 1975

VOLUME XI
EARTHQUAKE and DYNAMIC ANALYSIS

Edited by N. RADHAKRISHNAN



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by Automatic Data Processing Center
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Structural engineering--Congresses

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

DEMBO - The relation between the lateral force design procedures presented in "Seismic Design for Buildings" (TM 5-809-10) and those of more rigorous dynamic analyses are presented. It is noted in the paper that for the bulk of military structures, i.e., low, one- to three-story buildings, the design procedures given in the TM are valid. The limitations on the use of the TM and other similar codes are presented, particularly where functional considerations of the building are important. Trends in development of over

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20. ABSTRACT (Continued)

procedures for seismic design of buildings are discussed with emphasis on the response spectrum method. Examples of the use of the response spectrum for military structures are shown for hospitals designed for seismic response, and for protective structures designed for nuclear weapons effects. A discussion of earthquake risk in Eastern U.S. is presented and applied to military structure design for the Army Ammunition Plant Modernization and Expansion Program. The use of structural dynamic analysis computer codes is briefly reviewed with examples of the use of GENSAP for hospitals and SAFEGUARD/Site Defense military structures, FEDIA for nonlinear analyses, and STRUDL for military structures subject to dynamic loads due to accidental explosions. Recommendations on use of large dynamic analysis computer codes are given, and experience in the Huntsville Division with the use of structural analysis computer codes is summarized.

GUTHRIE - The conventional seismic coefficient method for the seismic design of concrete gravity dams is being supplemented by procedures coupling the computed dynamic response of the structure with the estimated future ground motion for the area. At present, both methods should be used to check the designs of new and existing hydraulic structures in high risk seismic zones. So far, precise standards have not been established for designating design earthquakes for an area or defining the requirements for a structure's dynamic performance. This paper reviews the present earthquake design procedures, which involve computing inertial, hydrodynamic, and dynamic earth forces. It describes the dynamic response procedures that are evolving from recent developments in earthquake engineering research. The paper also discusses earthquake engineering training courses and the available dynamic analysis computer programs, all of which use the finite element method.

PREFACE

In December 1974, the Automatic Data Processing (ADP) Center, Waterways Experiment Station (WES) submitted a proposal to conduct a Corps-wide Conference on Computer-Aided Design in Structural Engineering (CADSE) to the Office, Chief of Engineers (OCE). OCE approved the proposal and efforts were started in February 1975 to conduct this Conference. The Conference was conducted in New Orleans, Louisiana, 22-26 September 1975 and was attended by 175 engineers from 48 Corps field offices, OCE, Construction Engineering Research Laboratory (CERL), and WES.

This volume contains papers from Specialty Session G, State-of-the-Corps-Art on Earthquake and Dynamic Analysis. Mr. Lucian G. Guthrie, Structural Engineer (Civil Works), DAEN-CWE-D, OCE, was session chairman and presented a paper. Another paper was presented by Mr. Michael M. Dembo, Chief, Civil-Structures Branch, HNDED-CS, Huntsville Division.

The Conference was successful due to the efforts of a multitude of people. The roles they played were different but they were all directed toward making a concept on "instant dissemination" work. The Organizing Committee for the Conference consisted of:

COL G. H. Hilt, WES
Mr. F. R. Brown, WES
Mr. D. L. Neumann, WES
Mr. J. B. Cheek, Jr., WES
Dr. N. Radhakrishnan, WES--Conference Coordinator
Mr. W. A. Price, WES
Mr. G. S. Hyde, WES
Mr. D. R. Dressler, LMVD
Mr. W. B. Dodd, LMNDE
Ms. E. Smith, LMNDE
Mr. L. H. Manson, LMNDE

An OCE Coordinating Committee also worked enthusiastically to ensure the success of the Conference. This Committee consisted of:

Mr. C. F. Corns

Mr. R. L. Delyea

Mr. R. F. Malm, OCE Coordinator

Mr. L. G. Guthrie

Mr. D. B. Baldwin

Mr. R. A. McMurrer

The New Orleans District did a remarkable job in playing hosts to the Conference.

There were 13 division speakers, 25 moderators, two invited speakers, four technical speakers, and ten session chairmen, who shared the technical load of the Conference. Also, eight computer vendors showed their ware to the participants.

The editor would like to thank all the individuals who served on the committees and the speakers and the moderators for sharing their time and thoughts. Without them the Conference would not have been the success it was. Mr. Donald Dressler, LMVD, and Mr. William Price, WES, are especially thanked for their technical guidance and assistance.

This report was edited by Dr. N. Radhakrishnan, Research Civil Engineer, Computer Analysis Branch (CAB) and Special Technical Assistant, ADP Center, under the direct supervision of Mr. J. B. Cheek, Jr., Chief, CAB, ADP Center, and the general supervision of Mr. D. L. Neumann, Chief, ADP Center.

The Director of WES during the Conference and the preparation of this report was COL G. H. Hilt, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

EARTHQUAKE AND DYNAMIC ANALYSES FOR MILITARY STRUCTURES

by

Michael E. Dembo*

In addition to conformance to mission requirements and functional criteria, the objectives of design for military structures in a seismic environment include:

a. Prevention of serious injury and loss of life.

b. Minimization of property and equipment damage.

c. Insuring the continuity of critical services.

At present, structural designs for military systems are controlled by TM 5-809-10, "Seismic Design for Buildings." The TM closely follows the recommendations of the Lateral Force Requirements of the Structural Engineers Association of California (SEAOC), 1973. The Uniform Building Code 1973 and the SEAOC recommendations are closely related in all major aspects affecting seismic structural design. Inherent in these codes are the objectives stated above, with the further clarification in the TM of designation of structures by loss-potential. The equivalent lateral static force methodology is the basis of the design procedure described in the TM and the SEAOC. However, provision is made in all of these design procedures for more rigorous dynamic analysis procedures depending on the degree of asymmetry, complexity of the structural system, and distribution of loads.

The equivalent lateral force technique of the TM and SEAOC is described by the following equation:

$$V = ZKCW$$

where

V = the total base shear on the structure

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* Chief, Civil Structures Branch, Huntsville Division.

Z = a factor related to a seismic damage risk zone for the U. S. This factor does not appear in the SEAOC lateral force requirements

K = a factor which allows for the plastic deformation capabilities of various type structures.

C = the seismic coefficient; the critical factor in the equivalent lateral force technique which attempts to relate the base-shear force of the structure through the fundamental period of vibration of the structure

W = the total weight of the structure

The values of Z are shown in the following tabulation:

Values of Z

Zone	Regions West of 106° Longitude High Loss	Regions West of 106° Longitude Low Loss	Regions East of 106° Longitude High Loss	Regions East of 106° Longitude Low Loss
0	0	0	0	0
1	0.25	0.25	0.25	0.25*
2	0.50	0.50	0.50	0.50*
3	1.00	1.00	1.00	0.50
4	1.50	1.00	-	-

* Nominally anchor and laterally brace mechanical/ electrical elements in lieu of designing for specific lateral loads.

The relationship of the parameters given for the equivalent lateral force methodology to comparable factors in a conventional dynamic analysis (e.g., a normal mode analysis) are shown in the following table:*

* Ray W. Clough, "Dynamic Effects of Earthquakes," ASCE, Journal of the Structural Division, April 1960.

Table 1

Comparison of Dynamic Theory with SEAOC Code and TM

Dynamic Theory	SEAOC Code and TM
a. $V_n = \frac{W_n}{g} \frac{2\pi}{T} S_v$	a. $V = kCW$
b. $S_v = f(T)$ $W_n = \frac{\left(\Sigma \phi_{xn} w_x\right)^2}{\Sigma \phi_{xn}^2 w_x}$	b. $C = \frac{0.05}{\sqrt[3]{T}}$ accounts for: velocity spectrum, effective weight, higher modes, inelastic action
c. $F_{xn} = V_n \frac{\phi_{xn} w_x}{\Sigma \phi_{xn} w_x}$	c. $F_x = \frac{(V-F_t)\ w_x h_x}{\Sigma\ w \cdot h}$
d. Inelastic action greatly affects magnitudes of dynamic forces	d. $k = 0.67$ to 1.33 for buildings accounts for varying yield capacity of different types of construction

n = modal response number

T = natural period

S_v = maximum velocity produced in the structure by the earthquake motion. S_v is obtained from a velocity-response spectrum

ϕ = displacement of "x" floor level

x = floor level

F = force (lb)

At the risk of generalization, for the bulk of military structures (buildings) which are low, one- to three-story structures, the TM and SEAOC provide an effective procedure for seismic design. For multistory structures, the TM and SEAOC will, in general, underestimate the dynamic response in terms of story shears obtained through dynamic modal analysis. As noted earlier, where discontinuities in story stiffness exist in the frames resisting lateral loads, the ability of the Code to provide adequate lateral resistance is questionable. Further, the Code, by simulating the actual inertial forces by means of equivalent forces, does not represent the reality of the dynamic situation. For multistory structures, there can be major amplification of the ground motions resulting in significant forces in the main load carrying members. Codes such as the SEAOC and the TM are predicated on achieving minimum resistance; some damage is anticipated in moderate earthquakes. Finally, the evidence of the San Fernando earthquake in 1971 indicates that the functional aspects of a structure/facility must be considered in seismic design. Where necessary, a structure should be designed to remain operable subsequent to an earthquake of postulated magnitude. This implies that the nonstructural systems in such structures must remain functional. As an example, for hospitals, power generation and communication facilities should be designed to survive earthquakes with only minor interruption of their performance.

It is considered that the next advance in design of structures to resist seismic induced forces will be through use of the shock response spectrum. Major advances have been made in this area in recent time motivated by design considerations for nuclear reactors. In a report by Newmark, Blume, and Kapur, "Design Response Spectra for Nuclear Power Plants, Atomic Energy Commission, 1973," recommended response spectra for seismic designs are developed. These have been incorporated into the regulatory guides of the former Atomic Energy

Commission (Figures 1a-b).* The advantages of the spectral approach to definition of earthquake criteria include: (a) design spectra include the entire frequency range of interest, rather than merely the peak acceleration, (b) the spectral approach can be adapted to account for site conditions by using records obtained at sites with similar conditions, (c) the spectra can be used as input to a dynamic analysis of a structure by the mode superposition method. Where inelastic deformations are anticipated, it is necessary to use direct integration procedures.

Examples of military facilities designed by the Huntsville Division include industrial facilities similar to those illustrated subsequently in this report and certain facilities for the SAFEGUARD System. For the industrial facilities, the governing criteria were the previously referenced TM. In general, manual calculations were used, supported by ICES/STRUDL as required for framed structures. For SAFEGUARD, analyses of seismic response for shock isolation system were made for facilities intended to be constructed in the Great Falls, Montana, area. Nuclear weapons effects on structures are largely a "high" frequency phenomenon, i.e., acceleration responses induce the major forces in the structural members. Since this design approach holds for shock isolation systems as well, a check was made to verify that the low frequency motions induced by earthquakes would not exceed system criteria for allowable horizontal displacement of shock isolated platforms.

An interesting example of military facilities designed and analyzed for seismic loads are the Letterman and Hays General Hospitals located in California. Both these facilities are strongly influenced by the well-known San Andreas Fault in the San Francisco and Monterey Bay areas. Seismic analyses for the two hospitals have recently been made by the Construction Engineering Research Laboratory (CERL). An illustration of Letterman Hospital and an example of the

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* U. S. Atomic Energy Commission, Regulatory Guide, Revision 1, December 1973, Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants."

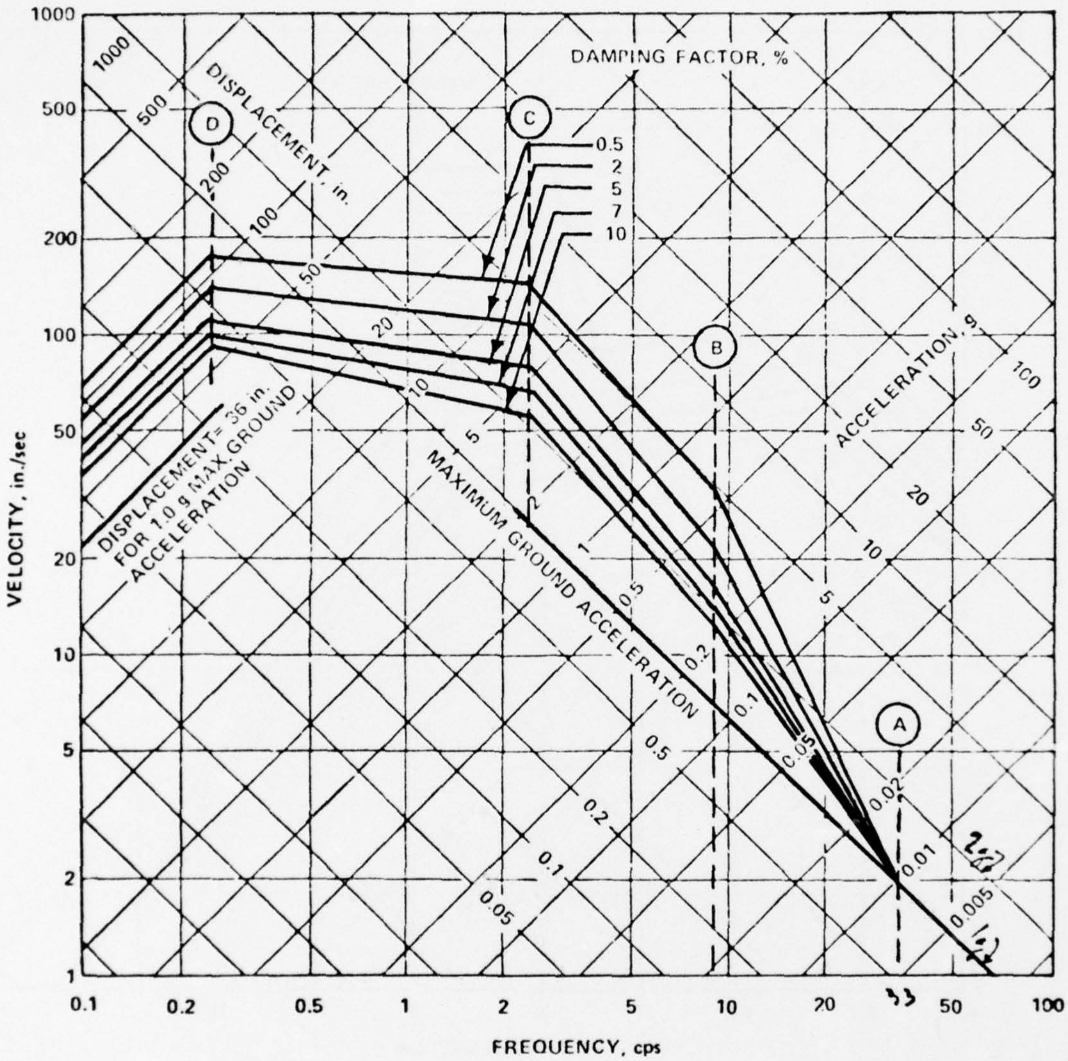

Figure 1a. Horizontal design response spectra:
Scaled to 1g horizontal ground acceleration

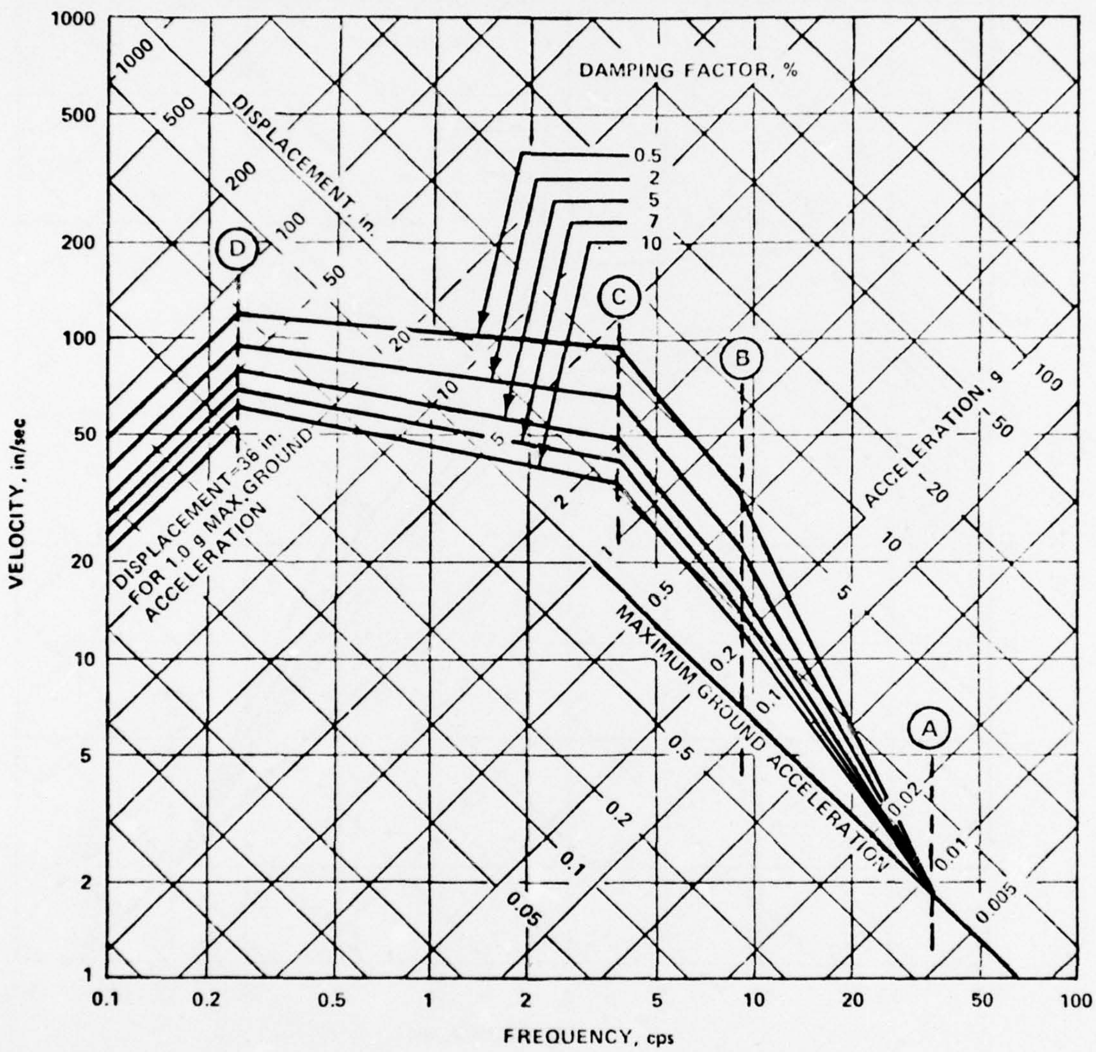

Figure 1b. Vertical design response spectra:
Scaled to 1g horizontal ground acceleration

modal response are provided in Figures 2 and 3, respectively. The following tabulation illustrates the extent of differences in response in terms of story shear provided by the different analysis routines.

Shear (in Kips) for 10-Story Hospital
Subjected to Typical Earthquake*

Story	Time History Analysis	Spectral Analysis	1968 SEAOC Code Design Value
10	7,517	6,511	725
9	11,675	10,085	1,194
8	17,246	14,080	1,546
7	20,547	16,470	1,780
6	23,090	18,380	1,899
5	24,894	20,600	2,919
4	25,890	22,760	3,779
3	30,896	29,020	6,429
2	37,559	32,780	7,814
1	39,000	33,290	8,554

* Agbabian Associates, Existing Capacity and Strengthening Concepts for Letterman and Hays Hospitals (Task 8), draft report (Construction Engineering Research Laboratory, April 1974).

For the hospital dynamic analysis, the GENSAP Code was used. This code is a version of the original Wilson SAP Code. GENSAP is a three-dimensional, elastic finite element computer program, which can solve static or dynamic problems. Arbitrary time-dependent kinematic or other forcing functions can be applied as input boundary conditions. The Code can solve the dynamic problem by direct integration or by the normal mode analysis procedure. A description of GENSAP is provided in Users Guide for GENSAP Code, May 1972, U. S. Army Corps of Engineers, Huntsville Division. Artificial time-dependent earthquake motions were developed based on analysis of site dependent soil

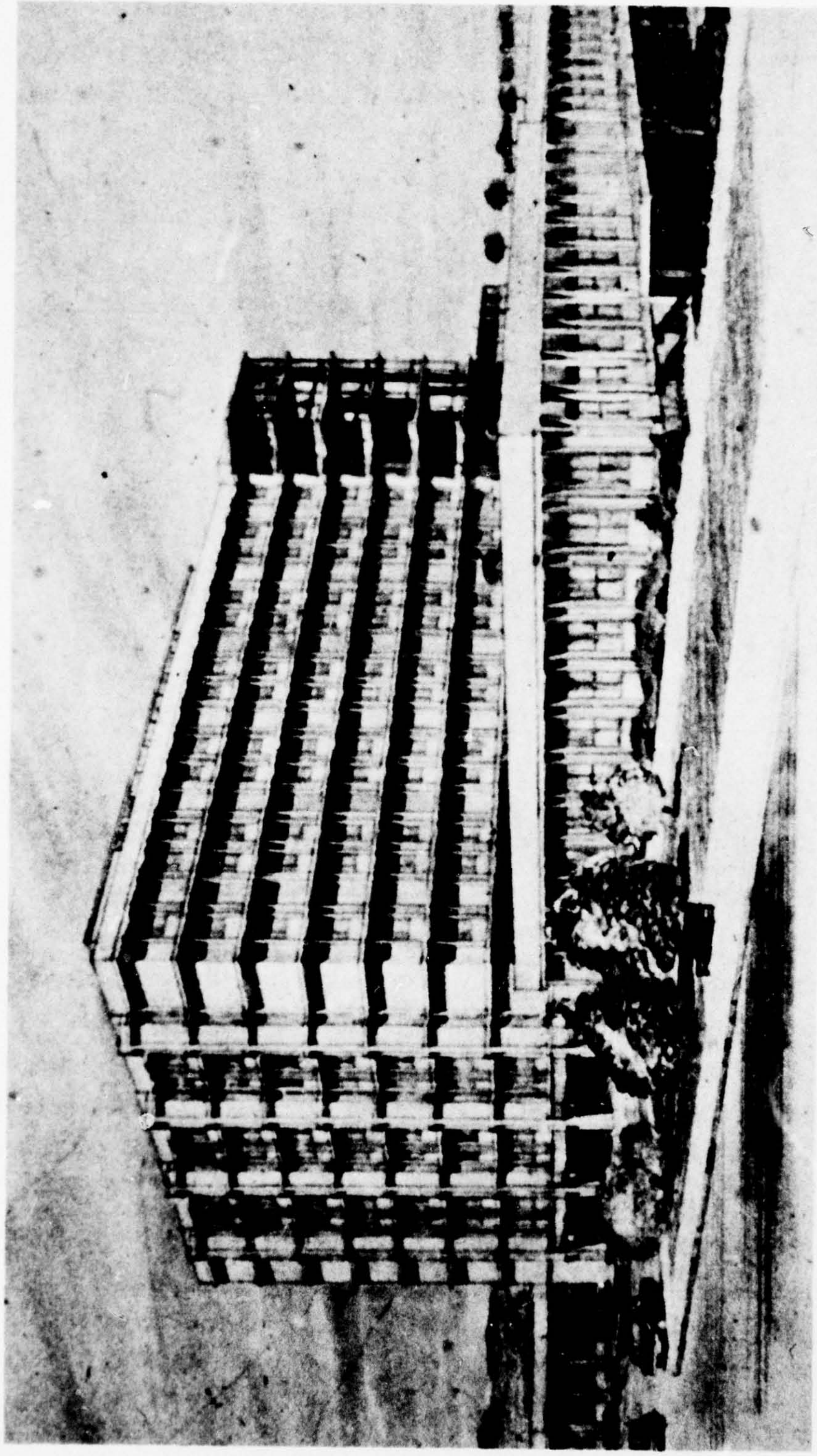

Figure 2. Letterman General Hospital, Presidio of San Francisco, California

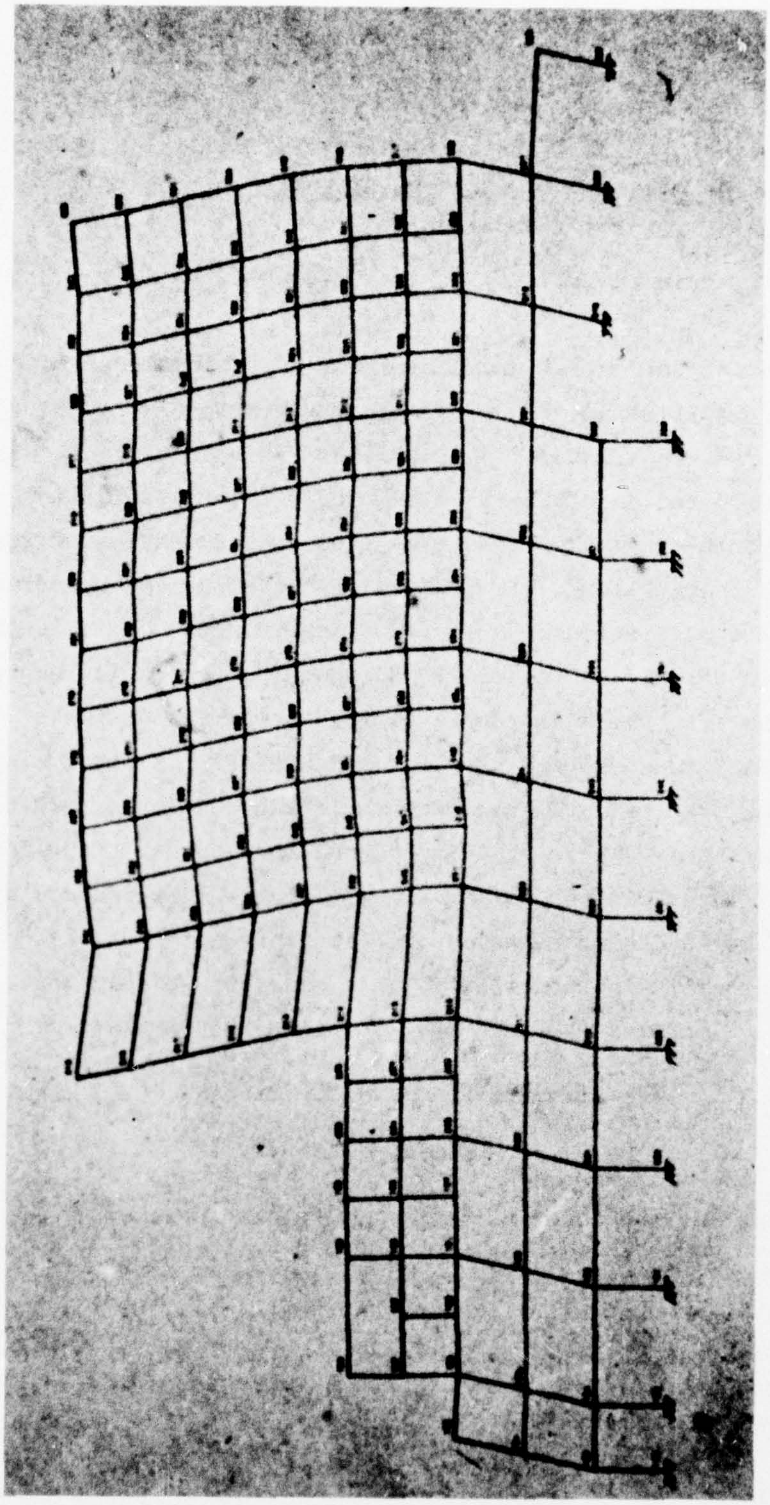

Figure 3. Second horizontal mode shape, N-S direction, Letterman Hospital

conditions and geology and were used as the driving functions in the mathematical models of the structures. A detailed analysis of the Letterman and Hays General Hospitals is given in "A Seismic Design Criteria - Rehabilitation of Existing Hospital Facilities, Task Report, Volume 1," by Agbabian Associates, Contract DACA23-73-C-0033, March 1974, for CERL.

A plot of seismic activity in the United States is shown in Figure 4.

In relation to Central and Eastern U. S., the main areas of seismic activity are noted in the Middle Mississippi Valley in the well-known New Madrid Fault Zone. Other areas of seismic activity which should be considered carefully in design of military facilities include the Southern Appalachians, the area around Charleston, South Carolina, and the New York, New England area (influenced by seismic activity in the St. Lawrence Valley). Figure 5 shows the location of Army Ammunition Plants as related to the zonal seismic risk map prescribed by the TM. Where appropriate, the facilities at these Ammunition Plants must be analyzed for seismic effects particularly concerning response of automated electronically controlled monitoring and control systems. These systems control the manufacturing and processing of hazardous chemicals and explosives. The control systems are susceptible to disruption due to the motions anticipated as a result of regional seismic activity. A summary of seismic activity in Eastern U. S. is presented in the following tabulation.

<u>Earthquakes - Eastern U. S.</u>

<u>Summary</u>

- Considering historic time, damaging earthquakes have occurred in most of Eastern U.S. (East of 105° Longitude)
- No major (Intensity IX) earthquakes since 1900
- Eastern U.S. damaging earthquakes fewer than Western; however, area of damage in Eastern U.S. greater than Western

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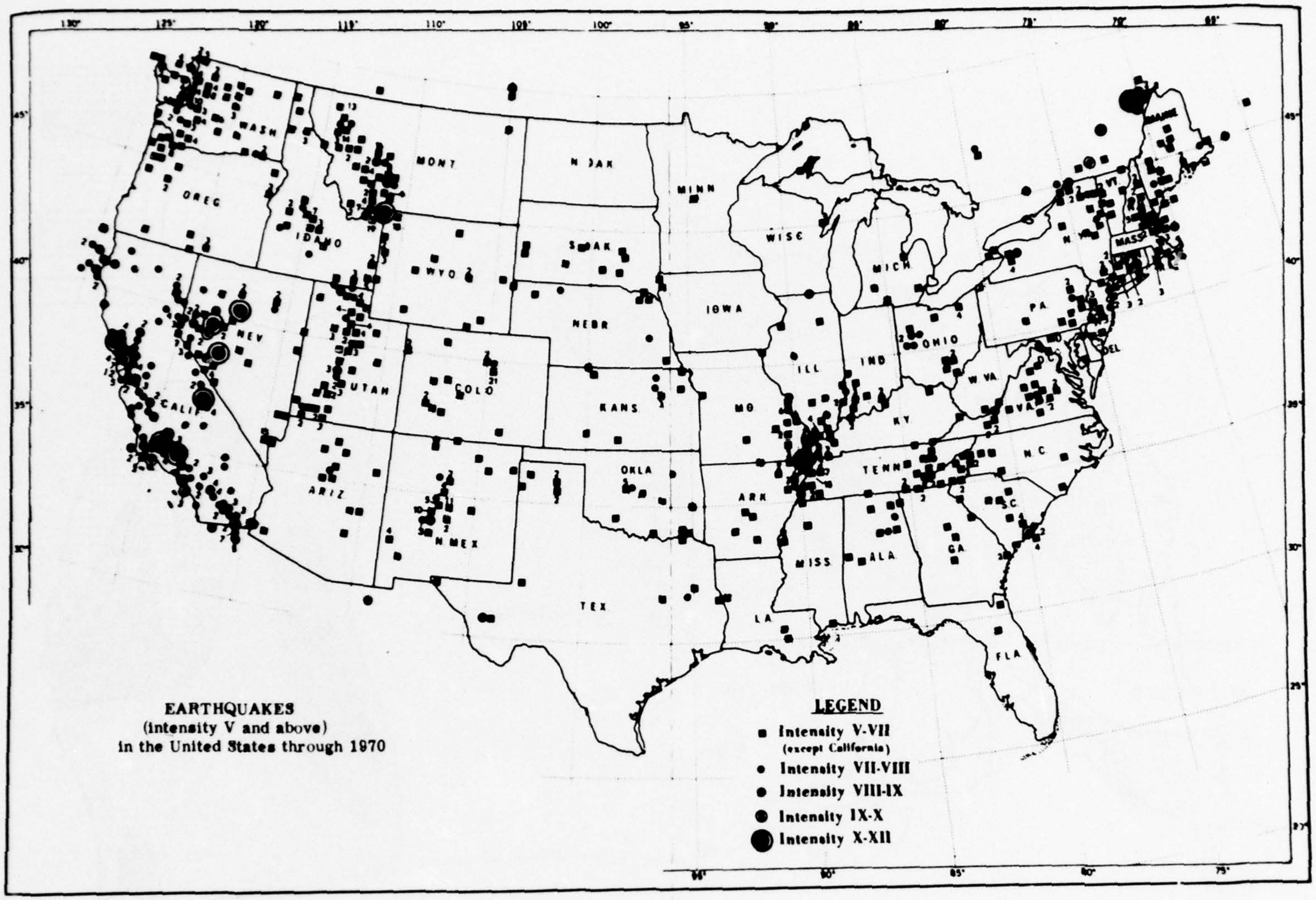

Figure 4. Seismic activity in the United States

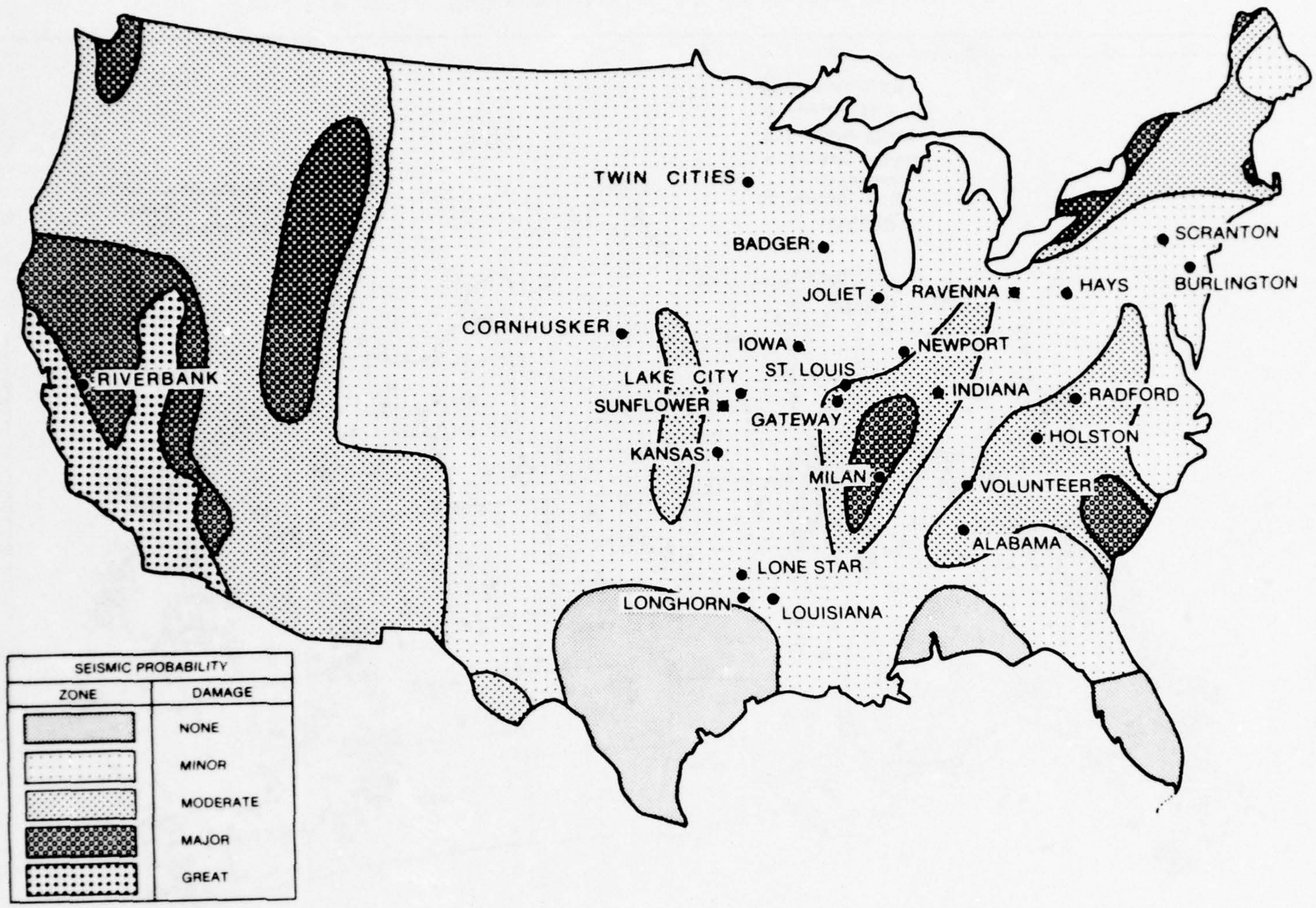

Figure 5. Seismic zone map of contiguous states

- In long time, damage risk in Eastern U.S. same as Western U.S.

o Recurrence (varies by area)

  - Intensity <IX - 50 years
  - Intensity IX - 75 years
  - Intensity IX-X - 150 years
  - Intensity XI - 500 years

o Areas of greatest concern:

  - Mississippi Valley (1895 - IX, 1968 - VII)
  - Charleston, S.C. (1886 - X)
  - Southern Appalachian Mountains (1957 - VI)
  - St. Lawrence Valley

o Statistically - a major damaging earthquake (≥VI) expected in Mississippi Valley in next 20 years

Dynamic Analysis in Military Construction

In addition to dynamic loads due to seismic effects, other time-dependent loads, which require application of dynamic analysis techniques, are the ground shock and airblast loads due to nuclear weapons effects and chemical explosions.

About 50% of the total energy of a nuclear explosion is released in the form of blast and shock. For military protective systems, the dynamic loading resulting on a structure is felt as airblast on exposed portions of the building and as ground shock on below-grade portions. In the SAFEGUARD System, the structures designed by the Corps which had to function during and after a nuclear attack, i.e., hardened, included: radar buildings (semiburied and above-grade), buried power plants, missile silos, and ancillary structures.

In all of these structures, system criteria related to allowable transient and permanent displacements, rotation, and tilt had to be met. Contained within these structures were radar and data processing equipment required for the command/control function. These equipments also had to be hardened. The result was the necessity for generating in-structure environments (dynamic response) containing information on its dynamic characteristics of a much more sophisticated nature than

would have been required for a strictly structural analysis to size the members. Information on dynamic response up to 100 Hz was required for design and testing of the electronic radar equipment. Permanent rotation and tilt of missile silos were limited to less than one degree from a longitudinal axis. Radar systems contained automatic displacement control mechanisms which require accurate determinations of the anticipated transient and permanent displacements. The result was the necessity for a rigorous dynamic analysis of the structure. A major research and development program supported the analysis and provided necessary empirical data to verify that required system hardness had been achieved. Figures 6 and 7 show longitudinal sections through the Missile Site Control Building and the Perimeter Acquisition Radar Building. A special characteristic of the loading function in SAFEGUARD was the time relationship of the ground shock and the airblast overpressure on the structures. Figure 8 shows a typical plot of the combined ground shock and airblast. Note the oscillatory nature of the ground motion environment (analogous to earthquake motions) and the more impulsive airblast characterized by the sharp acceleration spike.

The dynamic analyses of the structures were accomplished through several computer routines. In general, the generation of the frequencies, mode shapes, and associated dynamical matrices were accomplished using proprietary finite element programs. Figure 9 shows the finite element model for portions of the Missile Site Control Building. The development of dynamic force magnification factors for structural design and time-motion histories of response at selected locations were through programs created specifically for that purpose. At each floor, response spectra were developed for specified locations, the response spectra were then enveloped to cover an entire floor. Figure 10 shows a nondimensional example of the enveloping procedure. The Ralph M. Parsons Co. was the analyst for the Missile Site Control Building and Ammann and Whitney designed the Perimeter Acquisition Radar Building.

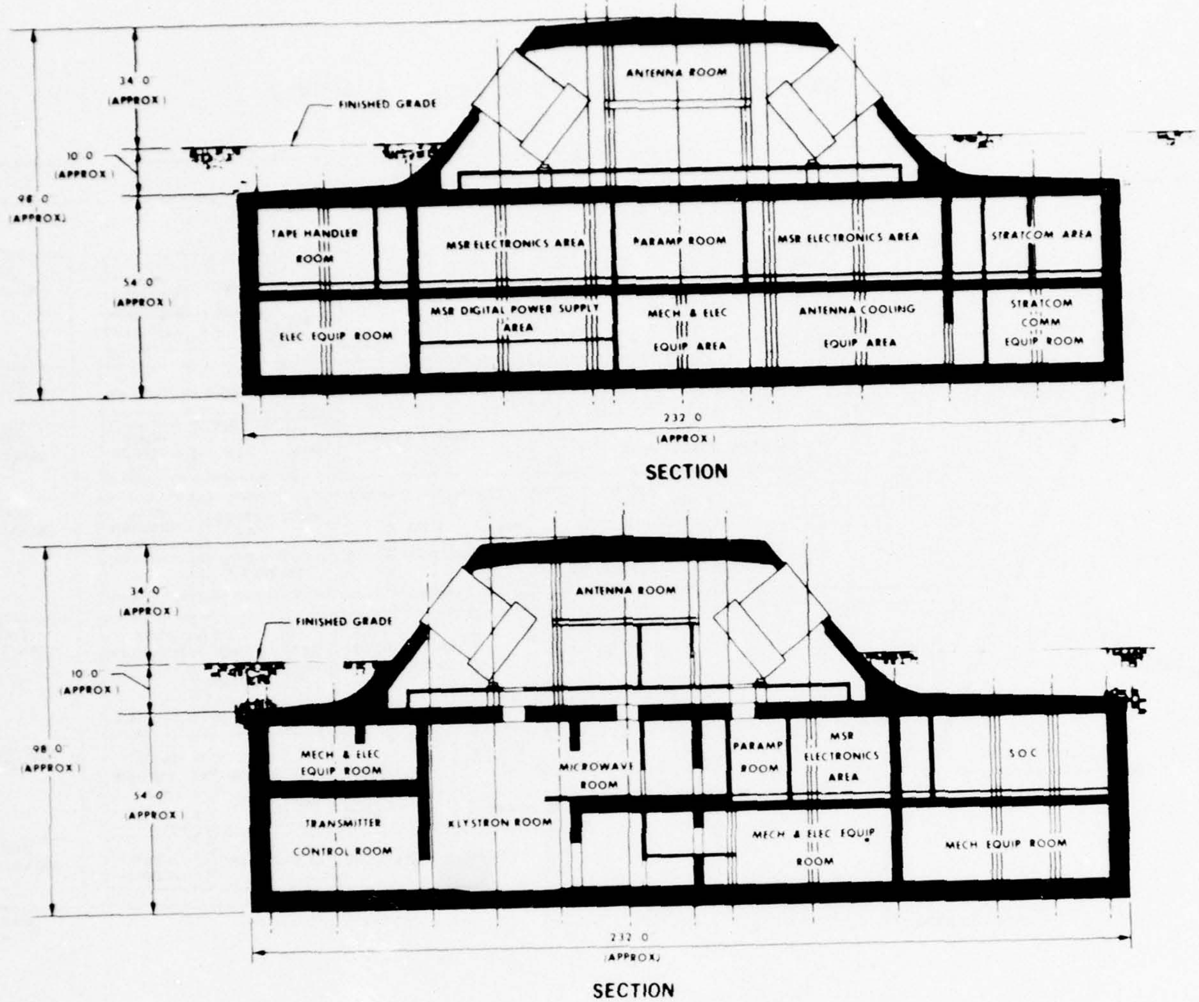

Figure 6. Missile Site Control Building Safeguard System

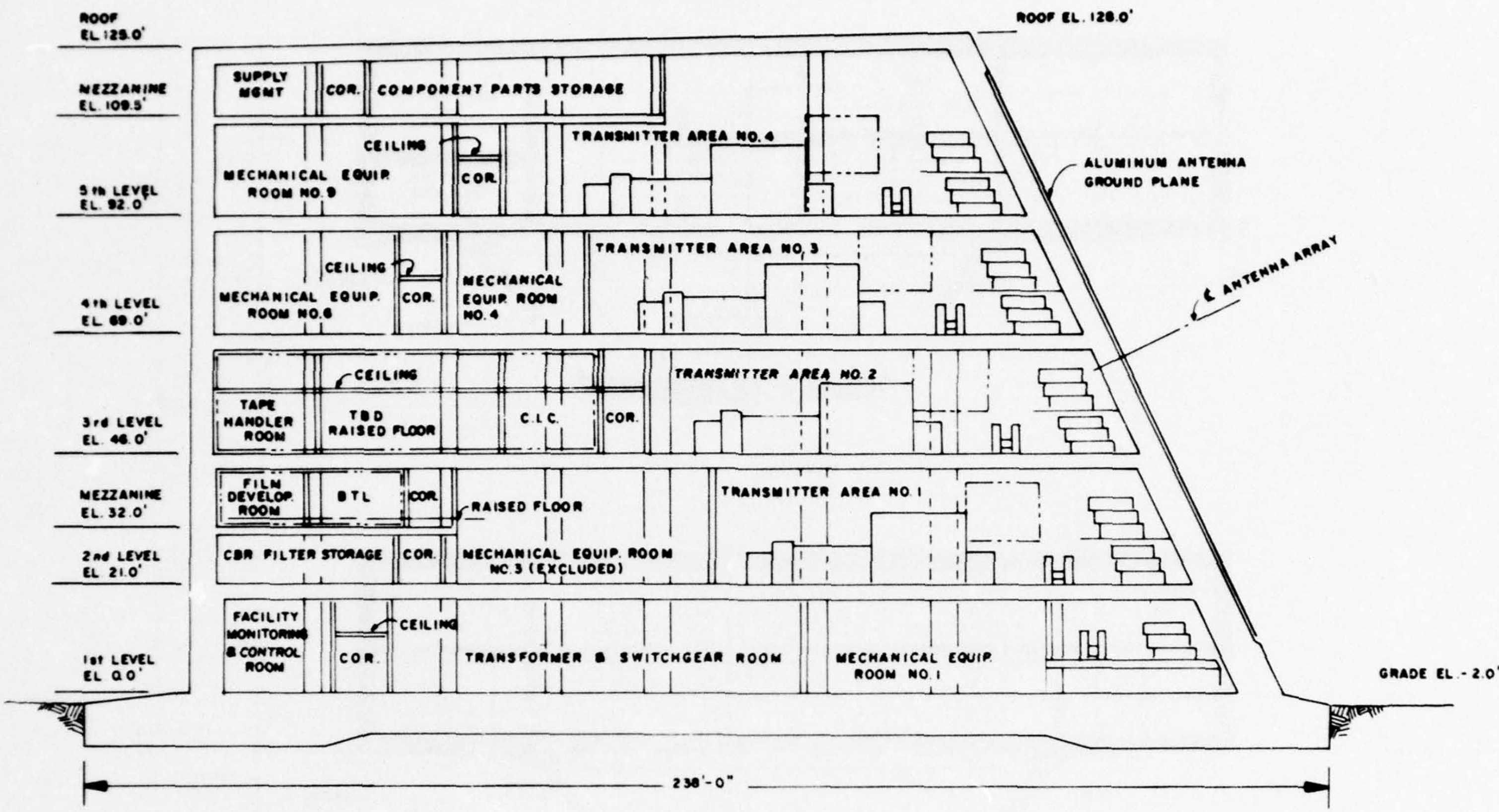

Figure 7. PARB cross section, SAFEGUARD System

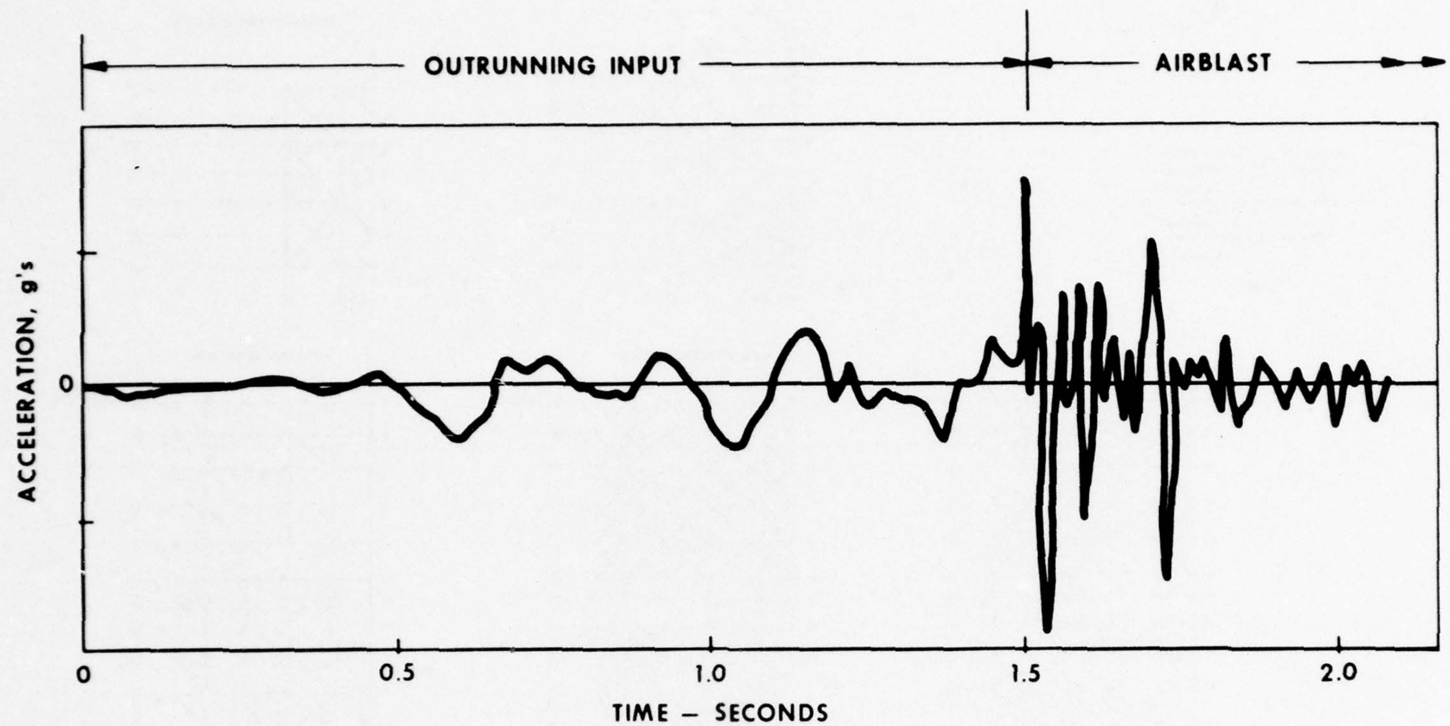

Figure 8. Typical acceleration responses of external wall, MSCB

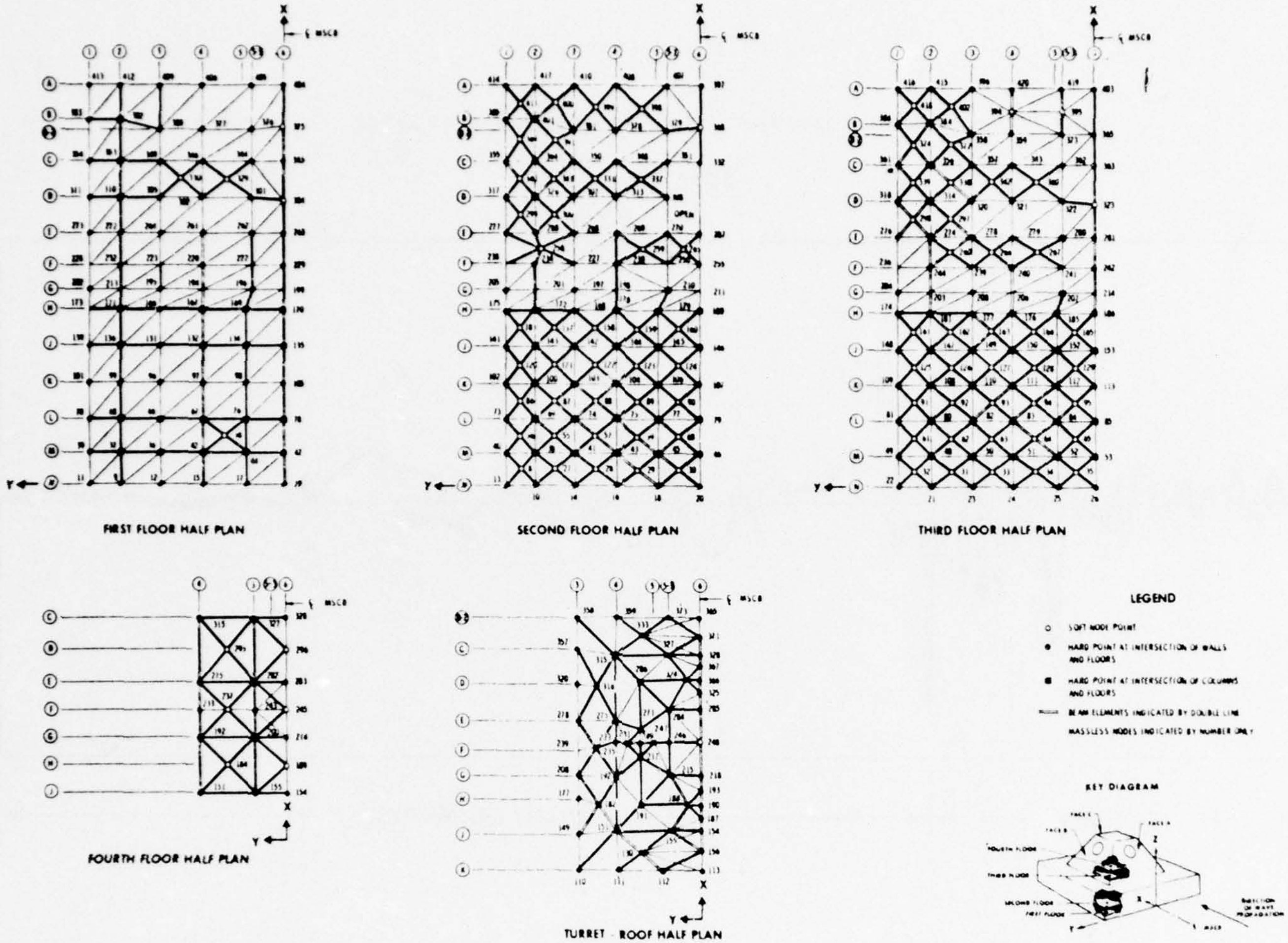

Figure 9. Mathematical model of the MSCB

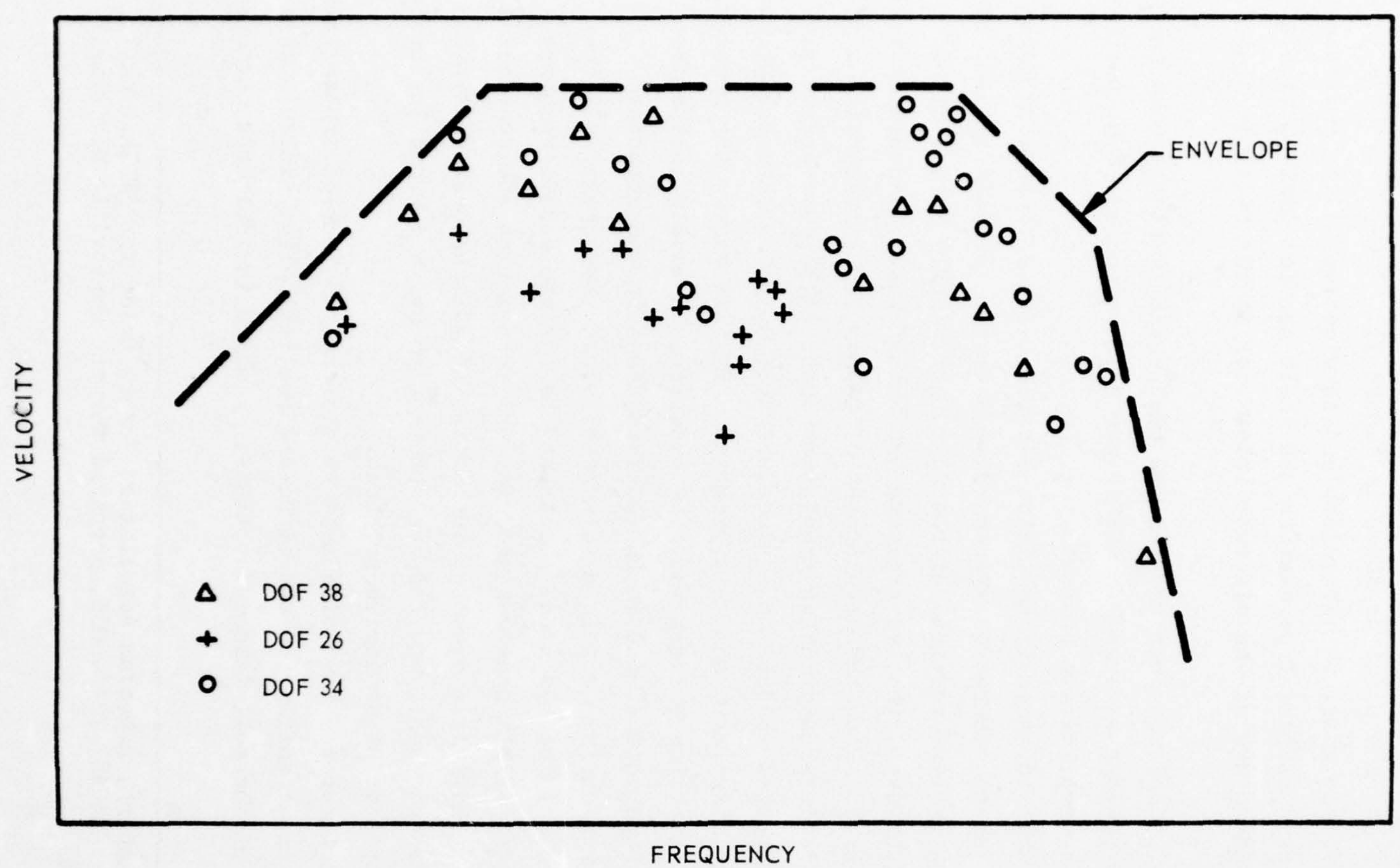

Figure 10. Response spectra of vertical motions of midspan mass points, second floor, MSCB

For SAFEGUARD, the connection of the mathematical model of the structure to the soil was through a discrete "spring dash-pot" interactor at each node point as shown in Figure 11. A major problem in the use of this model is the reliable determination of the stiffness and damping coefficient parameters and their spatial distribution. The main advantage of the discrete interactor is its relative simplicity.

The GENSAP Computer Program was not available at the time the SAFEGUARD designs were made. GENSAP was used for analyses as part of a hardness verification program.

Further advances in Ballistic Missile Defense technology have led to a second generation system, Site Defense. In this system, the radars are smaller versions of the SAFEGUARD Missile Site Control Building; however, the overpressure and ground shock hardness criteria are increased. With the development of GENSAP for structural analysis and a reliable ground motion prediction code, LAYER, a research program was started to develop a procedure to couple together the ground motion and structural analysis programs. By this means, the problems of incompatibility between the soil constitutive models in the free field (ground motion) and in the soil adjacent to the structure (as occurred during use of the discrete interactors previously described) should be resolved. To treat the inelastic soil response problem, the FEDIA* Code was used for the interaction and structural analysis. FEDIA is a dynamic, inelastic, two-dimensional continuous finite element code. The code can be used to solve dynamic inelastic axisymmetric or plane strain problems.

The first problem which must be overcome is that of transmitting criteria input motions to the structure realistically. This is done by means of the soil island technique, in which the criteria motions

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* J. Isenberg, Agbabian Associates, "Users Guide for FEDIA Code," Contract DACA87-73-C-0005, prepared for the Huntsville Division, May 1973.

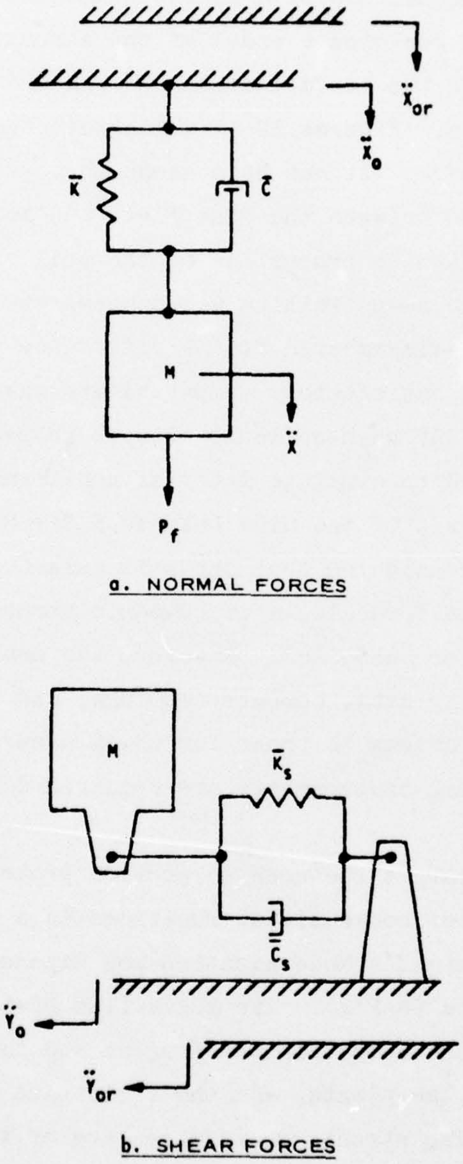

Figure 11. Soil/structure interaction model

are initially generated by a finite difference (LAYER Code) analysis. The motions along the boundaries of a fictitious soil island are stored during the finite difference calculation. These motions are then applied to the boundaries of a finite element soil island (GENSAP or FEDIA Codes) which contains a model of the structure; the airblast pressure is applied to the surface of the ground and to the exposed parts of the structure. Figures 12-14 illustrate the structure in the free-field halfspace. It has been shown that excellent compatibility can be achieved between the free field and soil island models so long as the constitutive properties of the soil are the same in both cases. Excellent compatibility was demonstrated between LAYER and FEDIA, inelastic axisymmetric finite difference and finite element codes, respectively. Satisfactory compatibility was demonstrated between LAYER and GENSAP when suitable elastic properties and damping coefficients were used to simulate material nonlinearity.

The final analysis of the Site Defense Radar Structure* is now in progress. It is considered that the soil island procedure offers a more reliable method for calculating dynamic structural response than that described for SAFEGUARD. However, the analysis, in terms of necessary supporting data, computer storage, and run times, will limit the class of problems to those for which accurate predictions of time-related dynamic environments are required for critical equipment designs.

Design of military structures to provide protection against accidental explosion of conventional munitions is a major feature of the Army Materiel Command's Modernization and Expansion Program for Army Ammunition Plants (AAP's). The Huntsville Division is the coordinating office for the Corps for the Program and is responsible for design of certain of the plants, and the validation of all blast resistant designs. The structures involved are of the industrial

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* Weidlinger Associates, "Analysis of Soil Structure Interaction on Site Defense (SD) Type Semi-Buried Structures, Parts I and II, Contract DACA87-74-C-0054, prepared for the Huntsville Division.

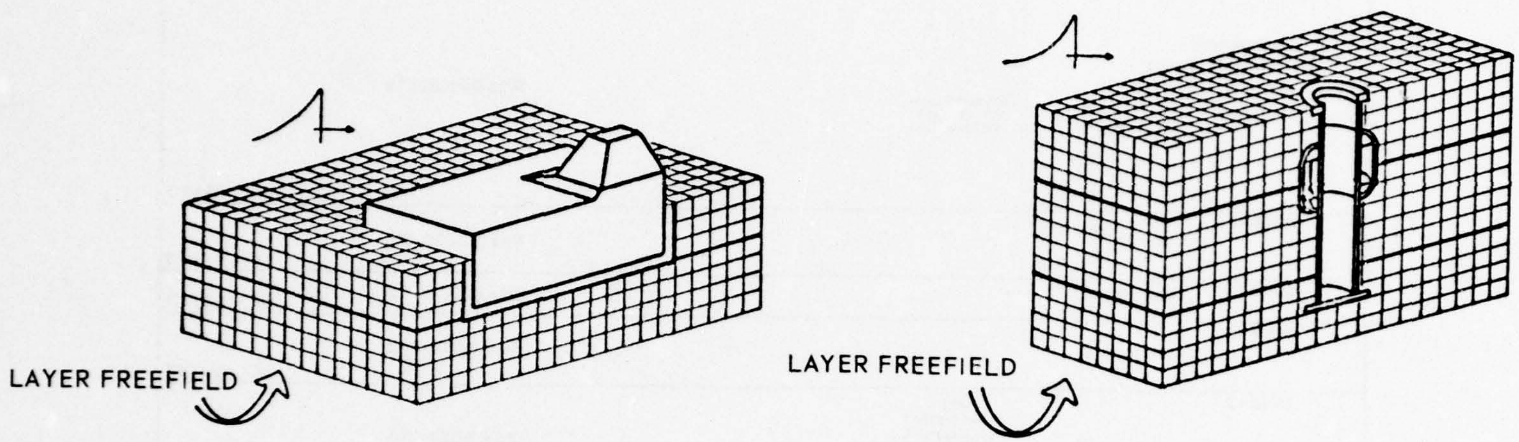


Figure 12. Typical problems

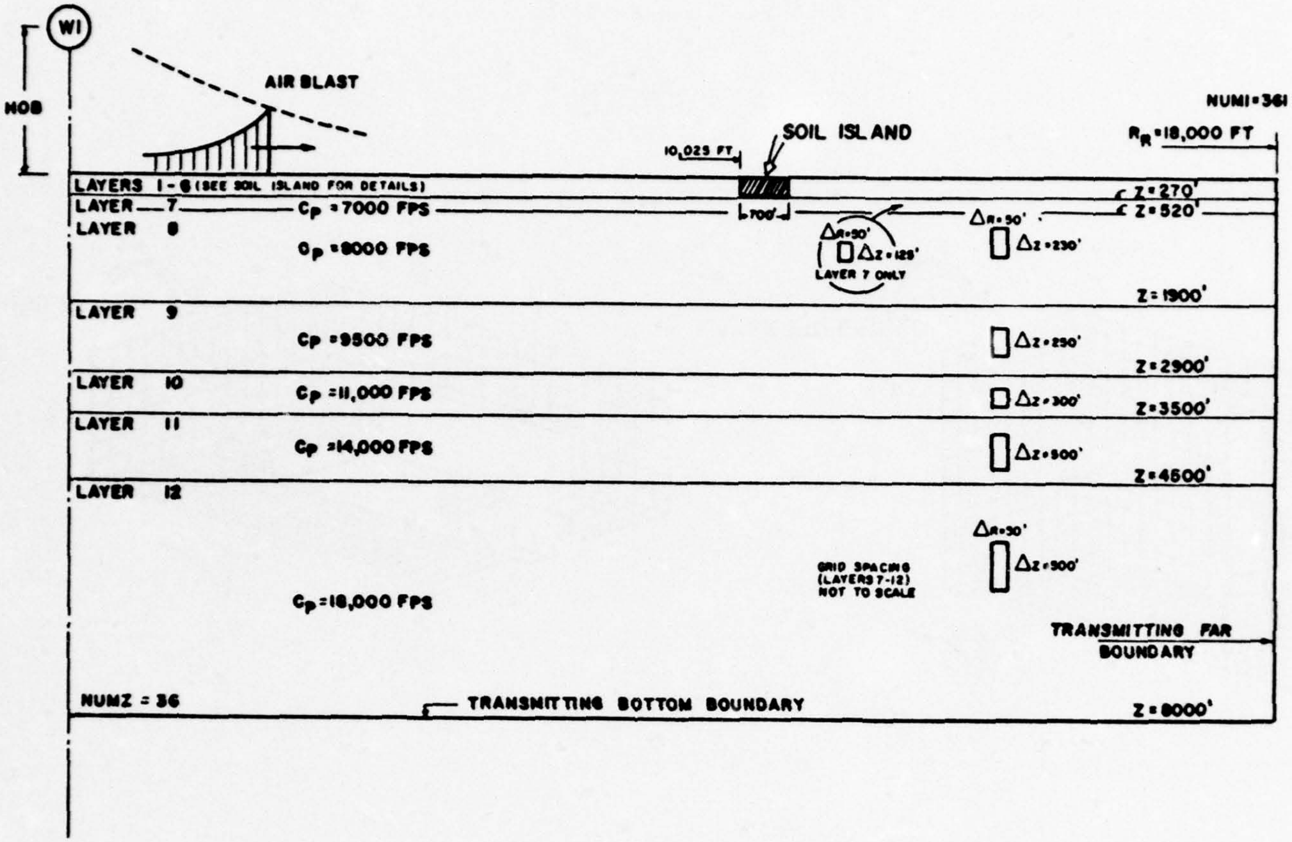


Figure 13. Geometry of free field calculation

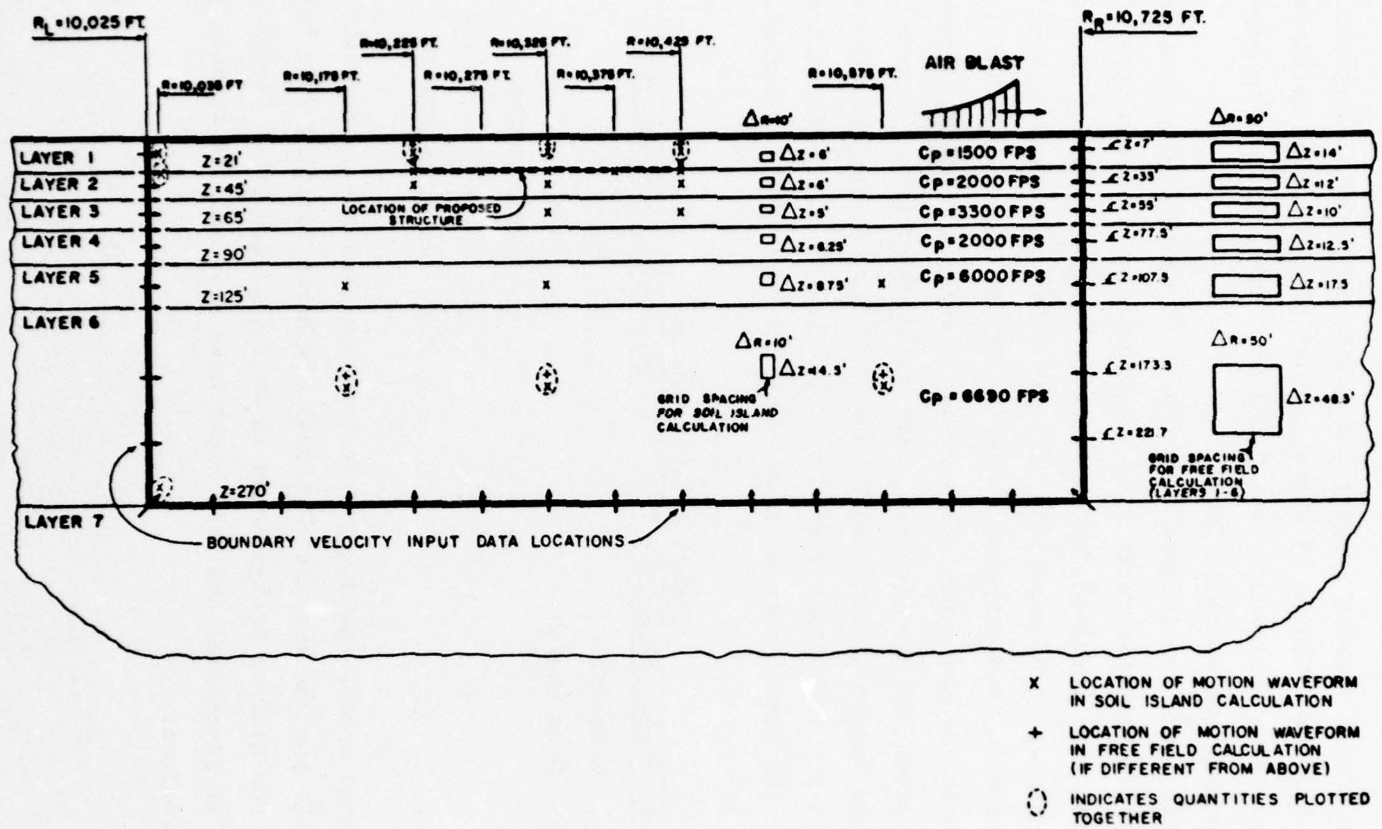


Figure 14. Soil island calculation, geometry, and location of motion waveforms

type and vary from built-up and prefabricated steel and concrete gable bents to steel frame structures of advanced design. The heaviest static loads in these structures are due to industrial floor loads, crane rails, metal forming presses and mills, and special supports for chemical processes. Figure 15 shows a model of the 105-mm Metal Parts Building now being designed by the Huntsville Division for the Lone Star Army Ammunition Plant in Texas.

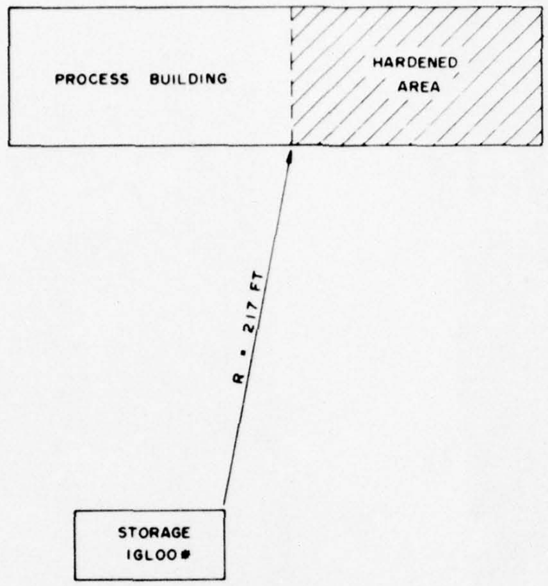
Dynamic loads are induced as a result of accidental explosions. Based on system criteria related to location, quantity, and type of chemical explosive involved, airblast overpressure loads are determined on the structures to be analyzed. Care is taken to determine load paths to the main load carrying members. In the Huntsville Division, STRUDL is used for the dynamic analyses. Figure 16 shows the procedure used for determining the airblast loads on the structure. Figure 17 indicates the design loading and Figure 18 shows the appropriate peak airblast and positive phase duration of the loads. The information produced by the STRUDL output is shown in the following tabulation.

STRUDL Analysis Output

Dynamic Characteristics	Time Dependent Response
a. Frequencies	a. Moments
b. Mode shapes	b. Shears
	c. Axial forces
	d. Joint deflections
	e. Joint rotations

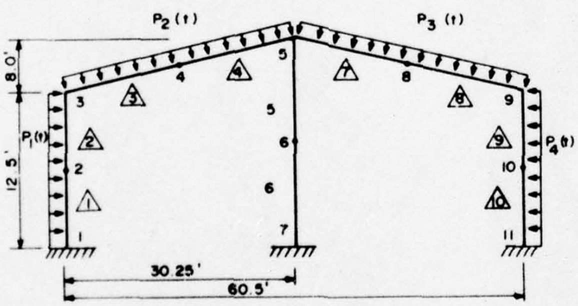
For wind loads, the Huntsville Division uses the appropriate Corps manuals and the American National Standards Building Code Requirements for Minimum Design Loads in Buildings and Other Structures. No particular structural analysis codes have been adopted to date for windload problems.

Figure 15. Model of 105-mm Metal Parts Building



* 1200 lb EXPLOSIVES (TNT EQUIV. = 0.60)

Figure 16. Accidental explosion (AAP M&E program)



STRUDL-DYNAL RUN # 1

MEMBER	JOINTS	MEMBER SIZE	Ax	Ix
1	1 - 2	W30x172	50.7	1950
2	2 - 3	W30x172	50.7	1950
3	3 - 4	W30x172	50.7	1950
4	4 - 5	W30x172	50.7	1950
5	6 - 5	W18 x77	22.7	1290
6	7 - 6	W18 x77	22.7	1290
7	5 - 8	W30x172	50.7	1950
8	8 - 9	W30x172	50.7	1950
9	10 - 9	W30 x172	50.7	1950
10	11 - 10	W30x172	50.7	1950

Figure 17. Process building frame (28.5-ft spacing)

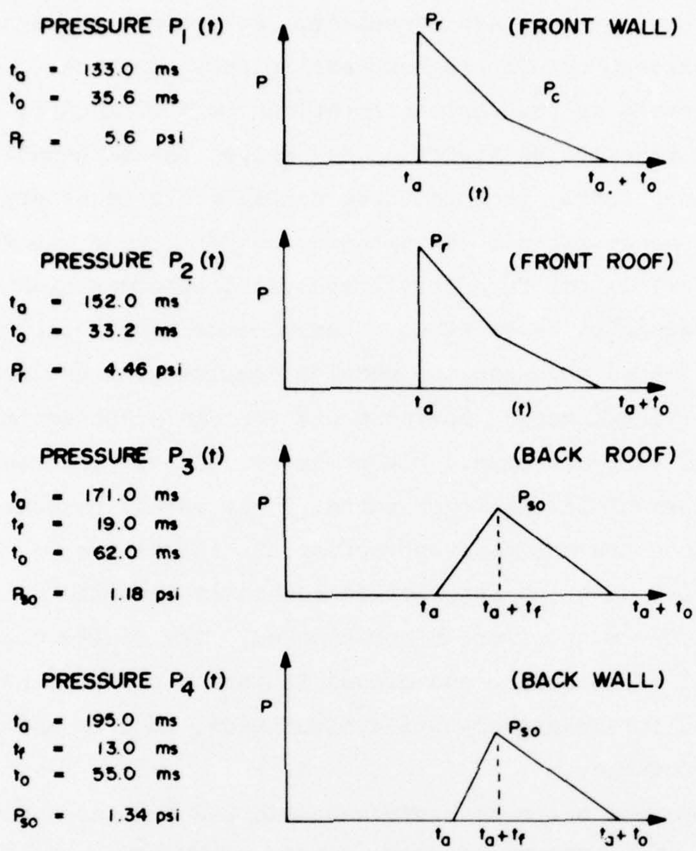


Figure 18. Load-time curves

Summary of Specialty Session

The TM 5-809-10, Seismic Design for Buildings, 1973, is an adequate tool for design of military facilities for structures (buildings) that are not critical (i.e., where there is no, or limited likelihood of loss of life, damage or requirement to replace expensive equipment, or disruption of critical services). The TM provides guidance here in the context of "high" and "low" loss potential. The manual is applicable to structures that are "simple," i.e., symmetrical or nearly so, and where there are no sharp discontinuities in "stiffness" (i.e., dynamic characteristics).

Where structures do not fall in the above categories, more

rigorous analysis routines are necessary. At present these can be accomplished through use of the response spectra approach to obtain acceleration levels at the various locations in a structure, or by application of time-motion histories to "drive" the mathematical model of the structure. In both these cases, it is necessary to perform a dynamic analysis. In the dynamic analysis, mode superposition provides a powerful tool for elastic analysis; determination of mode shapes and frequencies is critical. Lumped mass models can be used; however, where it is necessary to model a complex geometry or to obtain reliable in-structure environments for equipment design, the continuum model is preferable. Direct integration procedures must be used for cases of inelastic response. They should be used where the input motions are not constant across the foundation.

The "spring dashpot" interaction mechanism is valid for low frequency motions (e.g., from an earthquake). The finite element continuum model of structure and ground is more realistic, but may not be required for relatively stiff structures, such as military protective structures.

For frames which can be represented as 2-D models, a specialized purpose code such as STRUDL, GENSAP, ANSYS, or whatever, that will handle the problem is preferable to general purpose codes like SAP IV and GENSAP. The specialized codes are equally as efficient for the case at hand and are less expensive to use.

Care should be taken with the use of response spectra such as the Nuclear Regulatory Agency procedures since they may not be compatible with local soil conditions, i.e., a very soft or a very hard site, or a layered site with both soft and hard layers. The response spectra approach to dynamic analysis is more realistic in depicting the driving motions and resultant forces than the equivalent lateral load method.

Present proven tools for dynamic analysis are limited to the elastic case of complex structures. Some symmetrical or plane strain structures can be analyzed with confidence for inelastic response.

Even so, GENSAP or SAP IV provides a powerful tool for most Corps designs and analyses in military construction. The best features of SAP IV and GENSAP should be combined in one code and the duplication terminated.

General Comments

In Huntsville, good support exists from top management concerning computer use for structural engineering (other disciplines are negative).

The Tektronix or other interactive graphic hardware could be used to good advantage for military construction structural analyses and designs.

The reason is not clear, but in Military Construction, the percentage of work done in-house is small. This limits the ability to optimize use of computers for structural engineers.

The CDC 7600 has enabled the Huntsville Division to process our analysis and design work very efficiently--this hardware should be considered for Corps use.

The Huntsville Division has established an excellent working relationship with the U. S. Army Engineer Waterways Experiment Station (WES), in terms of both personnel and facilities. WES provides consultant service and "computer-oriented" personnel as required for special problems in the Huntsville Division.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. Charles F. Corns, Chief of the Structures Branch, Engineering Division, Civil Works Directorate, OCE, for permission to use parts of his presentation on earthquake design considerations given at the ASCE National Meeting on Water Resources Engineering, 29 January-2 February 1973, and Mr. C. D. Norman, Structural Research Engineer, Structures Division, Weapons Effects Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), for his contribution to this paper.

STATE-OF-THE-CORPS ART

IN

EARTHQUAKE AND DYNAMIC ANALYSES

FOR

CIVIL WORKS STRUCTURES

by

Lucian G. Guthrie*

Introduction

Procedures and methods for the seismic design of concrete gravity dams are presently changing from the conventional seismic coefficient method to procedures incorporating the computed dynamic response of the structure with estimated future ground motions. The latter method is a more rational one and couples the structure's dynamic properties and the characteristics of the ground motion.

Presently we are proposing to check the designs of new and existing hydraulic structures in high risk seismic zones by both the seismic coefficient and dynamic methods of analysis. The reason for requiring both methods of analysis is that there are still uncertainties involved in establishing the design earthquake(s) and setting the dynamic performance requirements of the structure.

The purpose of this paper is to review the present "state of the art" for the seismic design of hydraulic structures. The present earthquake design procedure is reviewed, the dynamic response procedures which are evolving from recent developments in earthquake engineering

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* Structural Engineer, Structures Branch, Civil Works Directorate Office, OCE.

research are described, and the earthquake engineering training courses and the available dynamic analysis computer programs are discussed.

Present Earthquake Design Procedure

Inertial forces

The present earthquake method of structural analysis for hydraulic structures is the seismic coefficient method. A selected seismic coefficient, which represents the ratio of an assumed acceleration of the structure to the acceleration of gravity, is multiplied by the weight of the structure to obtain the inertial force. The earthquake acceleration is assumed to act uniformly over the height of the dam. The minimum horizontal earthquake acceleration coefficients are 0.10 g for seismic zones 3 and 2, 0.05 g for seismic zone 1, and 0 for seismic zone 0 (ref: ETL 1110-2-109, 21 October 70).

The vertical earthquake acceleration effects are ignored. The reasoning behind this is that vertical acceleration changes the weight of the structure and the water in the same ratio. Considering these elements alone, the resultant is not displaced from the position it would occupy if there were no vertical acceleration. Also, uplift is assumed to be unaffected by earthquake accelerations (ref: EM 1110-2-2200, Gravity Dam Design, page 5).

Hydrodynamic forces

The hydrodynamic forces for gravity dams are computed by using the seismic coefficient in the Westergaard formula, which assumes the structure to be rigid. The method is based on the idea that the hydrodynamic force is of an inertia type and can therefore be represented as an added mass. The added mass, which is forced to vibrate with the dam, is represented by a body of water confined between a certain parabola and the upstream face of the dam (ref: EM 1110-2-2200, page 5).

For intake towers the increased water pressure is found by the added mass concept also. The seismic coefficient is multiplied by

the weight of the added mass of water which is assumed to be excited into motion by vibration of the tower. For a tower of circular section the added mass is equal to the mass of the volume of water displaced by the tower. For a tower of rectangular section the added mass is obtained from the volume of water in an imaginary solid of revolution. This "solid" is formed by rotating the vertical projection of the tower wall, which is normal to the direction of the seismic force, about a vertical axis through the centroid of the area (EM 1110-2-2400, Structural Design of Spillway and Outlet Works, page 27). In other words, the added mass is represented by a semicircular cylinder of water attached to each face of the tower normal to the direction of the earthquake acceleration.

Dynamic earth forces

The dynamic earth pressure magnitude for retaining walls is approximated by the Mononobe-Okabe method. In this method the seismic coefficient is multiplied by the weight of the Coulomb sliding wedge to produce the horizontal resultant earth pressure on the wall. The resultant is applied at 2/3 the fill height above the base. For a typical backfill material the dynamic earth pressure increase can be taken as about 10 and 20 percent of the static earth pressure for accelerations of 0.05 and 0.10 g, respectively. If there is a saturation level behind the wall, the hydrodynamic force is determined by the Westergaard formula (ref: EM 1110-2-2502, Retaining Walls, page 5).

Performance requirements

The performance requirements for hydraulic structures under these seismic loadings are specified principally in terms of overturning and sliding stabilities. For the normal operating condition with a seismic loading, the resultant location at any horizontal plane is allowed to be anywhere within the limits of the structure, so long as the allowable compressive stresses are not exceeded. The resultant location of the normal operating condition without the seismic loading has a "within the kern" requirement. The minimum shear-friction factor of safety is two and two-thirds for the normal operating condition with

seismic loadings, compared to a required minimum of four without seismic loadings.

Concrete stresses usually have not been a controlling factor in the design of gravity structures; in general an increase of one-third over the normal working stresses is permitted when seismic loading is combined with normal loads. Little attention has been paid to dynamic concrete tensile stresses under seismic loading. Acceptance of the resultant location outside of the kern of the section with earthquake loading, however, recognizes the existence of tensile stresses; rarely have computations been made to determine the stress magnitudes. Stress and stability analyses have usually assumed a condition of only compression normal to any horizontal plane.

Dynamic Response Procedures

The design earthquake

The principles and techniques for performing dynamic response analyses of dam structures have been available to the designer for a number of years. However, until very recently there has been a general reluctance to include such procedures in the design process, in part because of a lack of confidence in the suitability of the earthquake motion input data. Analyses for the most part used the recorded ground motion of some particular earthquake, such as the El Centro 1940 event, or idealized earthquakes, which were not necessarily compatible with local or regional geological features. However, substantial progress has recently been made in formulating procedures for estimating earthquake ground motions likely to occur at any specific location. Essentially, these procedures involve assessment of the seismic history of the region, the location and study of faults within the zone of influence, and stress-strain properties of the materials through which the seismic waves travel. From these evaluations, the "design earthquake" concept is formulated.

The design earthquake is assigned a Richter magnitude designation with corresponding values for peak particle acceleration, velocity, and displacement in bedrock at the epicenter. Then, using attenuation curves, reduced values of these ground motion parameters are estimated for the desired distance from the assumed epicenter. The duration of strong ground motion to be expected is estimated by the use of fault length and magnitude relationships.

Dynamic analyses

Two methods are being used in determining the response of structures to seismic induced ground motions. One method uses specified design earthquake accelerograms, and a time-history response of the structure is calculated. This is usually done for more than one accelerogram to account for variation in duration and frequency of strong motion shaking. For hydraulic structures, such as dams and intake towers, a complete time history of the dynamic response of the structure is computed by the finite element method.

The second method uses a design response spectrum rather than the complete time-history analysis. The design response spectrum represents the maximum response of all elastic damped single-degree-of-freedom systems subjected to design earthquake ground motion. One can enter a plot of such data at the structure's natural period and assumed damping to obtain the corresponding spectral (maximum) acceleration, velocity, or displacement of the structure in its fundamental mode of response. With the spectral acceleration, the mass of the structure, and the mode shape of the system determined, the magnitudes and distribution of the seismic induced forces on the structure can be computed. The mode shape is the nondimensional deflected shape of the structure for the mode of vibration under consideration. With the seismic forces applied, an equivalent static analysis is used to compute the dynamic stresses.

Since the response spectrum gives maximum response of a single-degree-of-freedom system at a particular frequency, exact response values can only be obtained directly for one mode. The reason for

this is that the maximum response for different modes does not occur at the same time. Adding up various modal maximum values therefore leads to overpredicting the overall structure response. A more reasonable method for predicting response due to several modes of vibration is to take the square root of the sum of the squares of the individual modal responses. However, for very stiff hydraulic structures, such as gravity dams, the first mode has the greatest effect on the dynamic response of the structure. The higher modes usually have a very small effect on the total response and can be ignored, at least for the approximate analysis.

For a more detailed explanation of the procedure for the response spectrum method, refer to Appendix A of this paper.

The hydrodynamic effect, including the dam-reservoir interaction and the compressibility of the water, which appears to be important for gravity dams, can be computed by the finite element method. For the response spectrum method, a simple procedure to account for the dam-reservoir interaction and the compressibility of the water is being developed and should be completed this fiscal year.

Performance requirements

The performance requirements for hydraulic structures with which to evaluate the results of a dynamic analysis have not been established. Current thinking is that, for a moderate earthquake which might reasonably be expected at the site during the life of the structure, the structure should be able to resist the dynamic forces produced without significant damage. For the greatest earthquake which can be expected, significant structural damage may be permitted insofar as such damage would not result in failure leading to loss of life and/or excessive property damage.

The dynamic properties of mass concrete and the foundation material under cyclic and reversible strains, which are representative of earthquake vibration conditions, need to be determined. This must be done before the results of a dynamic analysis can be evaluated properly with respect to the above performance requirements. In

particular, the dynamic tensile and shear strengths of mass concrete and the dynamic shear strength of the foundation are needed to assess the degree of damage the structure will sustain when experiencing the design earthquake.

Earthquake Engineering Research

The Civil Works Directorate of OCE is sponsoring an earthquake engineering research program which covers a wide range of problems associated with the earthquake behavior of gravity dams, arch dams, and intake towers. Finite element analyses and forced vibration field tests have been conducted on gravity dams and axisymmetric (circular in cross-section) intake towers by the University of California, Berkeley. These investigations included dam-reservoir and dam-foundation interaction, tower-reservoir interaction, and nonlinear studies on gravity dams. A finite element method of analysis, which will include the combined effect of the dam-reservoir-foundation interaction and seismic design recommendations for gravity dams and intake towers, is due to be completed by September 1976.

Finite element analyses, forced vibration field tests, and model studies have been conducted on an arch dam by the Weapons Effects Laboratory (WEL) at WES. Model studies of a gravity dam and the development of design aids to assist in the seismic analysis and design of gravity dams were initiated this fiscal year at WEL. The Concrete Laboratory at WES is conducting an experimental investigation on the dynamic properties of mass concrete.

A detailed discussion of the earthquake engineering research at Berkeley and WES is included as Appendix B of this paper.

The results of dynamic analyses of gravity dams made at Berkeley have focused attention on the limitations inherent in the present seismic coefficient method of analysis. An inspection and a dynamic analysis of Koyna Dam, which was significantly damaged by an earthquake in 1967, revealed the following. First, the earthquake acceleration

of 0.05 g, which was used in the design of the dam, is much smaller than the peak acceleration of 0.49 g that actually occurred at the site.

Also, the assumption that the seismic coefficient is constant along the height of the dam does not recognize that the coefficient should vary with the height according to the mode shapes and vibrations of the dam. Second, the higher strength concrete needs to be placed where the maximum dynamic tensile stresses occur, in the upper parts of the dam at the two faces, as illustrated in Figure 1. Third, the standard Westergaard hydrodynamic formula can grossly underestimate the hydrodynamic effects. One example showed a 50 percent increase in stresses due to hydrodynamic loads when the flexibility of the dam, dam-reservoir interaction, and compressibility of the water were included in the analysis.

Figure 2 shows results of the analysis of Pine Flat Dam due to the same earthquake. Pine Flat is a 400-ft-high dam, compared with Koyna's 340 ft, and has a higher and gentler change in the back slope. Even so, high tensile stresses occur near the slope transition.

Seismic Instrumentation

Records of actual earthquake motions and the response of dams to those motions are needed to check and improve dynamic response analyses. Recognizing this, the Corps of Engineers instituted a program several years ago to obtain such records. Concrete dams and intake towers in seismic zones 3 and 2 having heights of 150 ft or greater are being equipped with seismic instrumentation to measure future ground motion and the structure's response. Instruments include strong motion accelerometers, seismoscopes, and, in some cases, hydrodynamic pressure gages (ETL 1110-2-130, 30 July 1971).

Data from our seismic instrumentation program should increase our knowledge of earthquake ground motions and their effects on dam structures. As such data are obtained, procedures for design and analyses will be improved.

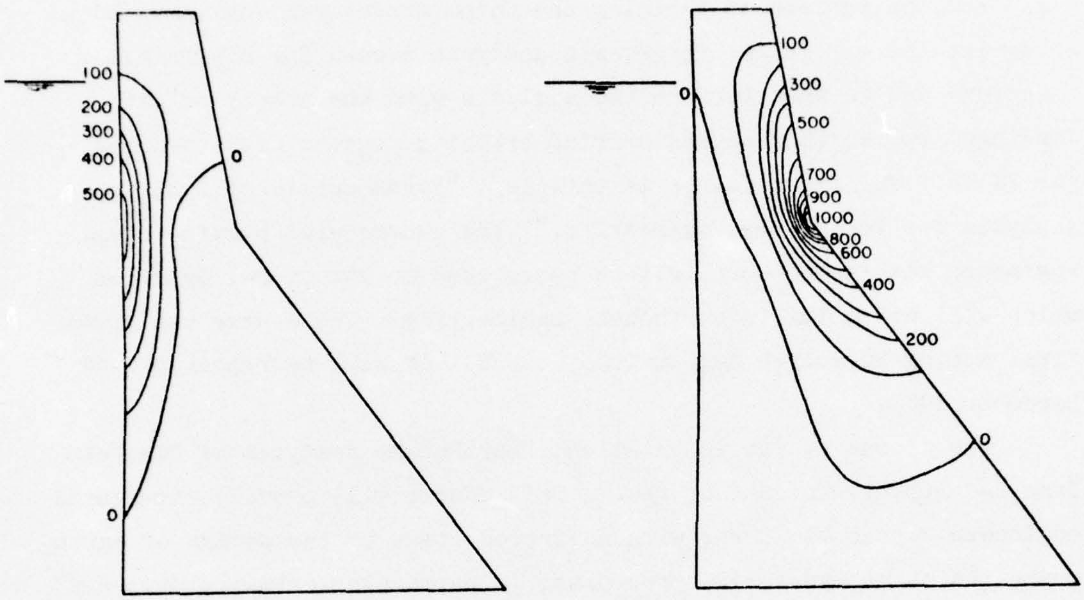

Figure 1. Critical tensile stresses in Koyna Dam due to Koyna earthquake

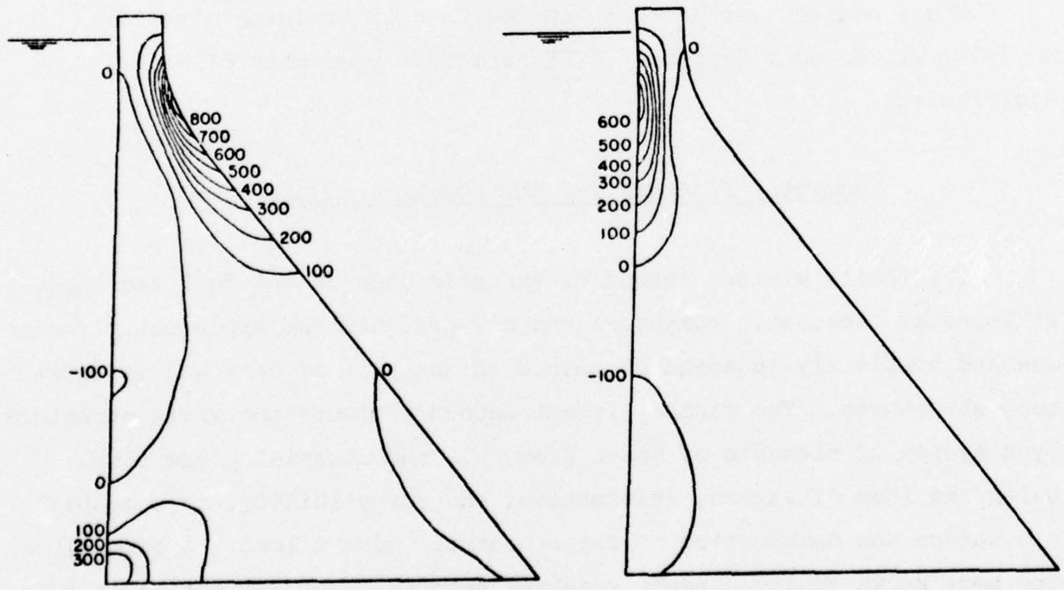

Figure 2. Critical tensile stresses in Pine Flat Dam due to Koyna earthquake

Earthquake Engineering Training

For the purpose of training the Corps structural engineers to recognize the extent of the seismic analysis needed for a particular structure and to then perform the analysis with the proper seismic loadings, two earthquake engineering training courses are scheduled for FY 76. The first course is entitled, "Fundamentals of Dynamic Analysis for Earthquake Engineering." The course will provide civil engineers within the Corps with a background in structural dynamics which will be useful in earthquake engineering. The course was given first during 28 July-8 August 1975 at WES. It will be repeated 1-12 December 1975.

The second course is entitled, "Earthquake Analysis of Concrete Dams and Appurtenant Structures." This course will provide structural engineers within the Corps with an introduction to the design of earthquake resistant hydraulic structures, in particular, gravity dams and intake towers. The course is scheduled to be given 19-30 January 1976 in San Francisco.

These courses are being announced in a CW training circular EC 350-2-91, dated 8 September 1975, which is presently being distributed.

Computer Programs for Earthquake Analysis

The finite element method of analysis uses to the full the capabilities of electronic computers and now presents the opportunity for a new and completely independent method of analysis of dams and appurtenant structures. The finite element method replaces the given structure by a system of elements of known geometric and material properties. Using the laws of stress, deformation, and compatibility, it computes the stress and deformation of the structure under a load. A summary of the best known finite element computer programs that are available for earthquake analysis of hydraulic structures is given below.

SAP IV

This is a general purpose structural analysis program for the static and dynamic analysis of linear structural systems. The program has proven to be a very flexible and efficient analysis tool. It is coded in standard FORTRAN IV and operates without modifications on the CDC 6400, 6600, and 7600 computers.

SAP IV can be modified and extended by the user. Additional options and new elements may easily be added. The program has the capacity to analyze very large three-dimensional systems; however, there is no loss in efficiency for the solution of smaller problems.

SAP IV is included in the WES Engineering Computer Programs Library Catalog, dated May 1975, and is operational on the G-635 computer at WES.

EADHI

This is a linear, two-dimensional finite element computer program for the earthquake analysis of gravity dams including hydrodynamic interaction. The Civil Works Directorate of OCE sponsored the development of the program. A brief description and references are given in Appendix B, page 57, of this paper.

EATSW

This is a linear finite element computer program for the earthquake analysis of axisymmetric intake towers, including interaction with the surrounding water. The Civil Works Directorate of OCE sponsored the development of the program. A brief description and references are given in Appendix B, page 58, of this paper.

ADAP

This is a finite element computer program for linear static and dynamic analysis of arch dam-foundation systems. The program uses most of the logical features of the computer program "SAP." Three different element types are included in the program; these are considered to be the most suitable elements for use in the three-dimensional analysis of arch dam systems. The program generates the finite element mesh of the system from a relatively small amount of

input data, performs a static or dynamic analysis of the system, and prints out the resulting displacements and stresses. The dynamic part of the program uses special numerical procedures that are shown to be very efficient in the analysis of arch dams.

For a detailed report on ADAP, refer to Report No. EERC 73-14, "A Computer Program for Static and Dynamic Analysis of Arch Dams," June 1973, Earthquake Engineering Research Center, University of California, Berkeley. The U.S. Bureau of Reclamation sponsored the development of the program.

NONSAP

This is a general purpose nonlinear finite element program which will solve static and dynamic, linear and nonlinear problems. Material and geometric nonlinear effects are included. The finite elements implemented have a variable number of nodes; these allow efficient mesh selection. The program can analyze one-, two-, and three-dimensional programs.

NONSAP is in the testing stage on the WES G-635 computer. For a detailed report on the program, refer to Report No. UC SESM 74-4, "Static and Dynamic Geometric and Material Nonlinear Analysis," February 1974, Structures and Materials Research, Department of Civil Engineering, University of California, Berkeley.

GENSAP

The GENSAP (General Elastic and Nonlinear Structural Analysis Program) program is a general purpose computer program for three-dimensional analysis of structural systems using the finite element approach. The program consists of three separately executable codes: PRESAP, the preprocessor package; RSPNSE, the main program; SAPOUT, the postprocessor package. The PRESAP and RSPNSE Codes are based on the SAP Code which was developed under the direction of Professor E. L. Wilson at the University of California at Berkeley. However, several important modifications and additions, such as the direct integration and nonlinear dynamic methods, have been included in the PRESAP and RSPNSE Codes. SAPOUT is entirely a new code and is

intended to provide the postprocessing capabilities for the RSPNSE Code. These codes have been executed successfully on the Univac 1108 and CDC 6400 digital computers.

GENSAP has been extensively used by the Huntsville Division. The program is included in the WES Engineering Computer Programs Library Catalog, dated May 1975.

Seismic Design Criteria of USBR and TVA

U. S. Bureau of Reclamation (USBR)

The seismic design criteria for USBR dams are covered in Engineering Monograph No. 19, "Design Criteria for Concrete Arch and Gravity Dams," U. S. Department of Interior, Bureau of Reclamation, dated September 1974. These criteria state that dams should be analyzed for the "Maximum Credible Earthquake." This earthquake is considered to be the most severe earthquake that could possibly occur at active faults which are located in the area of the site.

Guidance is given on the development of the design response spectrum and/or the design accelerogram. The analytical methods used to compute natural frequencies, mode shapes, and structural response will be described in the USBR publications "Design of Arch Dams" and "Design of Gravity Dams," which are scheduled to be published shortly.

Until more experimental information is available on the dynamic properties of mass concrete, USBR recommends that the instantaneous modulus of elasticity be used for dynamic effects. No recommendations are given for dynamic concrete strengths.

Minimum factors of safety for the "Maximum Credible Earthquake" loading condition are given for stresses and sliding stability. The factor of safety is 1.0 for concrete compressive and tensile stresses and 1.3 for the compressive stresses in the foundation. The minimum shear-friction factor is 1.0 within the dam or at the concrete-to-rock contact and 1.3 at a plane of weakness within the foundation. However,

no recommendations are given for dynamic concrete and foundation strengths, which would be needed for computing the safety factors.

Tennessee Valley Authority (TVA)

TVA's present seismic design procedure for hydraulic structures involves (a) establishing the design earthquake by a study of the seismic history and geology of the region of influence, (b) determining the earthquake loadings by the response spectrum method, and (c) using a static analysis for determining the stability of the structure.

For the earthquake loading condition the stability criteria require that a minimum of one-half the base be in compression. It is assumed that the tensile strength of the material is zero and that the compressive stresses do not exceed a 50 percent increase over that allowed for normal operating conditions. The minimum shear-friction factor of safety is 4, which is the same as that for normal operating conditions. TVA has found that if a minimum of one-half the base remains in compression, the shear-friction factor of safety when using static-type shear strengths does not control for the earthquake loading condition.

Conclusions

It should be recognized that the present seismic coefficient method of analysis is, at best, only an arbitrary allowance for potential seismic loadings. It is based upon precedent rather than on a rational basis. Neither the dynamic characteristics of the structure or the dynamic nature of the ground motion resulting from an earthquake are considered. The adopted seismic coefficients for design are not representative and often give magnitudes lower than peak acceleration magnitudes associated with anything but small or moderate earthquakes. However, the performance requirements are considered conservative, and this may compensate, in part, for the inaccuracies of the method.

For better simulating the actual response of a structure due to earthquake ground motion, dynamic response procedures are used. These

procedures involve establishing the design earthquake(s), performing the dynamic analysis, and determining the structural performance requirements with which to evaluate the analysis results.

The procedure for establishing the design earthquake involves assessing the seismic history of the region, locating and studying faults within the zone of influence, and determining the stress-strain properties of the materials through which the seismic waves travel. Establishing a design earthquake requires the use of considerable judgement.

Dynamic methods of analysis better simulate the dynamic response of the structure and the dynamic nature of the ground motion. A finite element analysis based on calculation of the time-history response of the structure to several appropriate ground motions (accelerograms) will provide the most information. This method can include the structure-reservoir and structure-foundation interaction and the structural response to the higher modes of vibration.

The response spectrum method of analysis will provide the maximum dynamic response of the structure in the fundamental mode of vibration. The dynamic response of the higher modes and the structure-reservoir interaction effects can only be approximated. It can be seen that the response spectrum method does not provide as much information on the dynamic response of the structure as a time-history calculation by the finite element method. The uncertainties involved in estimating the design earthquake and in estimating the expected frequency of occurrence of earthquakes are probably much larger than the errors introduced by using the response spectrum method. Therefore, the response spectrum method can be justified in many cases.

The performance requirements of hydraulic structures and dynamic material properties need to be determined before the dynamic analysis results can be evaluated properly. The rational use of dynamic methods of analysis requires a reasonably good knowledge of the performance of structures under dynamic stressing, that is, the degree of damage that the structure will sustain when experiencing ground motion of a given intensity.

Earthquake engineering research investigations on the seismic resistance of gravity dams, and, possibly, intake towers, and the seismic instrumentation program will continue to provide improvements in dynamic response procedures.

Earthquake engineering training courses will provide an effective channel through which knowledge of the dynamic response procedures can be transferred to the design engineers.

Computer programs are available for calculating complete time-history responses of structures to ground motions. However, before nonlinear dynamic analyses can be made with confidence, the dynamic material properties of mass concrete and the foundation material need to be better defined.

Appendix A: Procedure for Response Spectrum Method of Analysis

Estimate of Fundamental Frequency and Deflected Mode Shape of Initial Trial Section

In using a response spectrum for design of gravity dams or intake towers, it is first necessary to compute the natural frequency and corresponding mode shape for the trial section. In most cases, these parameters should be determined from finite element methods or generalized curves produced by such methods. More approximate procedures, such as Rayleigh's method for an equivalent lumped-mass system, can be used. When these are used, first comparisons show errors on fundamental frequencies to be 10 to 15 percent, as compared to the finite element predictions.

When the more approximate methods are used, it is very important to include the effects of shear deformation. Also, considerable improvements in mode shape and frequency can be obtained by iteration and increasing the number of lumped masses in the equivalent structures. It should be remembered, when using response spectrum techniques, that the natural frequency and mode shape are the first structural parameters calculated. In this sense, they will play an important role in other calculations, such as relative deflections, hydrodynamic pressures, shearing forces, and moments.

Estimate of Earthquake Forces from Design Spectrum

Once a response spectrum has been constructed for the design earthquake, the earthquake forces acting on the structure can be determined. Since we will represent the structure as a system with discrete lumped masses, there will be an inertia force acting on each individual mass. The sum of these inertia forces must be resisted by the shear at the base of the structure. For an individual lumped mass, this force might be determined from:

$$F_i = \Gamma_i M_i S_a \phi_i$$

where

M_i = lumped mass

$$\Gamma_i = \frac{\Sigma M_i \phi_i}{\Sigma M_i \phi_i^2}$$

$S_a = S_a\ (T,\ \xi)$, maximum acceleration of equivalent SDOF system as determined from response spectrum. (ξ: damping ratio) (T: nat. period)

ϕ_i = characteristic shape of fundamental mode.

Γ can be referred to as a modal participation factor. This factor represents the difference in the response of the equivalent SDOF system (i.e., the system used in developing the response spectrum) and that for a system with several lumped masses M_i. Each system is being driven by a prescribed base acceleration. From the distribution and magnitude of these earthquake forces, bending moments and shearing forces at various elevations in the structure can be determined.

Appendix B: Earthquake Engineering Research on Gravity Dams, Intake Towers, and Arch Dams

University of California, Berkeley

A linear two-dimensional dynamic finite element method of analysis for gravity dams that includes the dam-reservoir interaction effects has been developed.[1,2] The dam is treated as a finite element system and the reservoir is treated as a continuum governed by the wave equation. The horizontal and vertical components of the ground motion are taken into account.

A linear dynamic finite element method of analysis which includes the structure-foundation interaction effects has been completed.[3] The procedure was developed for a dam-foundation interaction problem but is applicable to other interactive systems commonly encountered, such as nuclear reactors idealized as axisymmetric structures, or general three-dimensional structures. The dynamic effects of the reservoir are not included in this analysis.

A nonlinear two-dimensional dynamic finite element method of analysis has been developed for gravity dams.[4] A mathematical model of the concrete dynamic properties is proposed. Approximate assumptions had to be introduced in the model due to the lack of experimental testing of mass concrete under dynamic cyclic and reversible strains. The nonlinear analysis is approximated as a sequence of successively changing linear systems. It considers biaxial stress conditions, the inelastic properties of concrete, the initiation and progression of cracking, and strain rate effects. The responses to horizontal and vertical components of ground motion are simultaneously computed. The dynamic effects of the reservoir and the interaction with the foundation are not included in the analysis. It should be pointed out that this study is an initial step in the development of a nonlinear dynamic analysis for gravity dams. The mechanical properties of concrete need to be better defined before the extent of cracking and its effects on the safety of gravity dams can be determined with confidence.

Forced vibration tests were conducted on Pine Flat Dam, a 400-ft high concrete gravity structure.[5] The natural frequencies and mode

shapes obtained from the prototype tests were compared with a three-dimensional finite element analysis of the entire dam and a two-dimensional finite element analysis. SAP, a general structural analysis program, and the finite element program, which includes dam-reservoir interaction, were used for the three- and two-dimensional analyses, respectively. The three-dimensional model appeared capable of yielding the natural frequencies and mode shapes of the dam with reasonable accuracy after the dynamic modulus of elasticity of concrete for the dam was estimated to be 3.25 million psi. The two-dimensional model's prediction of the decrease in the fundamental natural frequency of the dam with increasing water level was shown to be valid.

A linear finite element method of analysis for axisymmetric intake towers, including interaction with surrounding water, has been developed.[6] Only the horizontal component of earthquake acceleration is computed. The vertical component of earthquake acceleration causes, essentially, no lateral response of slender cantilever structures. The commonly used "added mass" approach to account for effects of surrounding water is examined. The design of intake towers is discussed. A computer program user's guide is included.

Forced vibration tests were conducted on the San Bernardino intake tower.[7] The added mass effects could not be calculated from the experimental results with sufficient accuracy to verify analytical procedures for determining added masses due to surrounding water. However, the analytical and experimental water pressure distributions were found to match.

A summary of the investigation of the earthquake resistance of intake towers is included in Reference 8.

U. S. Army Engineer Waterways Experiment Station (WES)

Prototype tests and two series of model tests were conducted on the North Fork Dam by the Weapons Effects Laboratory at WES. The prototype structure is a constant-angle arch dam having a maximum height of 155 ft and a crest length of 620 ft. The data obtained

from both the model and prototype compare quite favorably with that predicted from the three-dimensional finite element analysis. The initial model test and finite element analysis were described in Reference 9. The report on the second model tests is scheduled to be published prior to 1 January 1976. The final report, which will include the results of the prototype tests, should be published prior to July 1976.

To develop the much needed dynamic material properties of mass concrete, the Concrete Laboratory at WES is conducting dynamic tests on 8-in. diameter by 16-in. long cores drilled from blocks of mass concrete with a maximum size aggregate of 3 in. The tests consist of uniaxial tensile and stress-reversal tests in the 1- to 10-cps range.

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APPENDIX A: SUMMARY OF EARTHQUAKE AND DYNAMIC ANALYSES SPECIALTY SESSION

The two papers written on the state-of-the-Corps art in earthquake and dynamic analyses for military construction and civil works projects were briefly summarized and discussed. In the first session the paper concerning military structures was presented by the author of the paper, Mr. Michael E. Dembo, Chief of the Civil-Structures Branch, Huntsville Division. In the second session the same paper was presented by Mr. Washington T. Char, Chief of the Structures Section, Huntsville Division. The paper on the seismic design of civil works structures was presented at both sessions by the author of the paper, Mr. Lucian G. Guthrie, Structural Engineer, OCE, Civil Works Directorate, Engineering Division, Structures Branch.

Thirty-two conference participants attended the first session and thirty-one the second. These numbers include the moderators.

Mr. Dembo's summary of his paper concerning military structures included the limitations of the equivalent lateral static force methodology contained in TM 5-809-10, "Seismic Design for Buildings", the response spectrum and finite element time-history methods of dynamic analysis, computer programs for dynamic analysis, seismicity in the Eastern United States, and nuclear weapons effects.

Mr. Guthrie's summary of his paper concerning hydraulic structures included the present seismic coefficient method of analysis, the response spectrum and finite element time-history methods of dynamic analysis, earthquake engineering research, instrumentation, and training courses, and computer programs for dynamic analysis.

During the discussions which followed, the following points were made:

a. In order to use the finite element method (FEM) efficiently, preprocessors and postprocessors for handling the input and output data are a must.

b. A significant improvement in the latest finite element general purpose structural analysis computer program SAP IV could be made, possibly, by including in SAP IV the preprocessing and postprocessing capabilities of the earlier developed general purpose structural analysis computer program GENSAP.

c. A computer system with a capability of that of the CDC 7600 is greatly needed for dynamic analysis computer programs.

d. Before a finite element computer program is used by a District for structural analysis, the engineers using the program need to be knowledgeable of the finite element theory and well trained in the use of the computer program. The formation of a group of several engineers within a District who specialize in the use of computer programs deserves consideration.

e. Guidance on the dynamic material properties of mass concrete is needed now for evaluating the results of dynamic finite element analyses of dams and appurtenant structures.

f. Guidance on the selection of design earthquakes is needed now for use in the response spectrum or finite element dynamic analysis methods. Two sources of guidance were mentioned. They are the progress report, "Seismic Risk Analysis, California State Water Project," by Professor Haresh C. Shah of Stanford University given 30 January 1975 at the California Water and Power Earthquake Engineering Forum and the Construction Engineering Research Laboratory Technical Report M-114, "Guidelines for Developing Design Earthquake Response Spectra," June 1975.

g. The seismic resistance of hydraulic gates, such as tainter gates and miter gates, should possibly be investigated by dynamic analysis methods.

h. It is very important that a substantial part of the Corps design work be done in-house in order to maintain the Corps design capability.

i. TVA has had considerable experience in the seismic design of nuclear power plants by the response spectrum method.

j. The Structural Design Language (STRUDL) computer program may be used for the dynamic analysis of the simpler framed structures instead of GENSAP. STRUDL is easier to use.

APPENDIX B: BIOGRAPHICAL SKETCHES OF AUTHORS

Mr. Michael M. Dembo graduated from City College, New York, in 1948 with the Bachelor of Civil Engineering degree. He earned an M.S. in civil engineering from Northeastern University, Boston, 1953. He also did graduate work in structural engineering at Catholic and George Washington Universities, Washington, D. C., and at the University of California at Los Angeles. He worked as a structural engineer for private industry in Boston, 1948-1958. In the Corps since 1958, he has been Chief, Structures Section, at the District level; Chief, Protective Structures Development Center, Ft. Belvoir, Virginia; Chief, Research and Development Branch, and Chief, Civil-Structural Branch, Huntsville Division. He is a Registered Professional Engineer in Massachusetts, a Fellow of the ASCE, and a member of the Earthquake Engineering Research Institute. Mr. Dembo has written technical papers on protective structures design and the shock testing of equipment in protective structures.

Mr. Lucian G. Guthrie graduated from the Georgia Institute of Technology in 1961 with a Bachelor of Civil Engineering degree. For 10 yr he worked in the Nashville District as a structural design engineer. During this period he received a Master of Science degree in structural engineering from Vanderbilt University through the Corps Advanced Training Program for Engineers, Geologists, and Architects. Since 1972 he has worked in OCE, Civil Works Directorate, Engineering Division, Structures Branch. His main responsibilities in OCE have been planning and monitoring the Civil Works structural engineering research and training programs.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Corps-Wide Conference on Computer-Aided Design in Structural Engineering, New Orleans, La., 1975.
[Proceedings ... held in New Orleans, Louisiana, 22-26 September 1975] Vicksburg, Miss., Automatic Data Processing Center, U. S. Army Engineer Waterways Experiment Station, 1976-
12 v. illus. 27 cm.
Contents.-v.1. Management report.-v.2. List of computer programs for CADSE.-v.3. Invited speeches and technical presentations.-v.4. Division presentations.-v.5. State-of-the-Corps-Art (SOCA) reports on gravity monoliths, U-frame locks, and channels.-v.6. SOCA reports on gates, stoplogs, and trashracks.-v.7. SOCA reports on single- and multiple-cell conduits and tunnels.-v.8. SOCA reports on pile foundations and sheet pile cells.-v.9. SOCA reports on sheet pile walls and T-walls.-v.10. SOCA reports on stiffness methods, frames, and military construction.-v.11. SOCA reports on earthquake and dynamic analyses.-v.12. Interactive graphics, SEARCH and CORPS systems.

(Continued on next card)

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